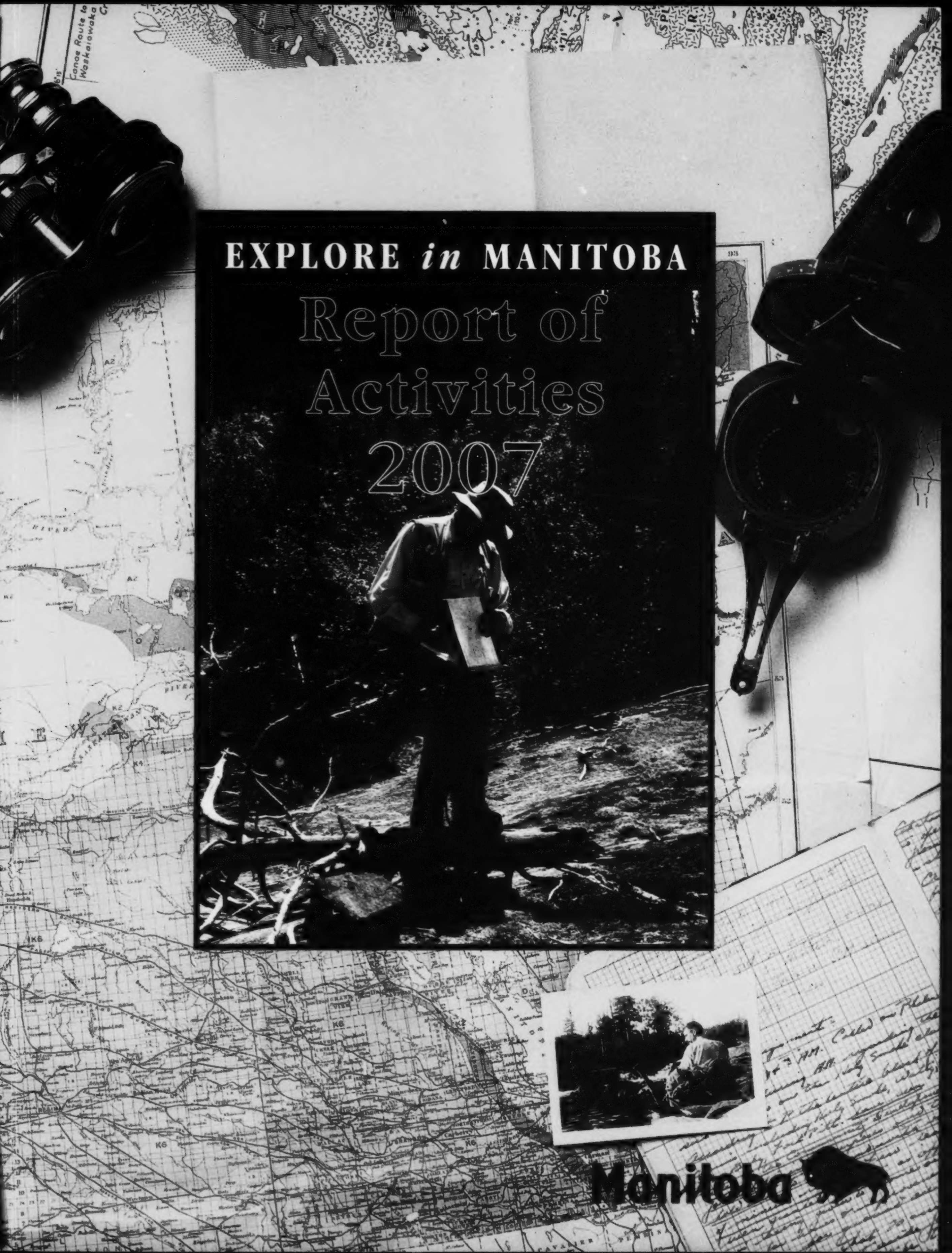

EXPLORE *in* MANITOBA

Report of Activities 2007

Manitoba

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2008-01652/

REPORT OF ACTIVITIES
2007

Manitoba Science, Technology, Energy and Mines
Manitoba Geological Survey

Manitoba

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Cover photo: Ric Syme, Director of the Manitoba Geological Survey (MGS), at Utik Lake, Manitoba where the MGS continued bedrock mapping in the northwestern Superior Province to reassess the mineral potential of this region (*see* GS-10, this volume).

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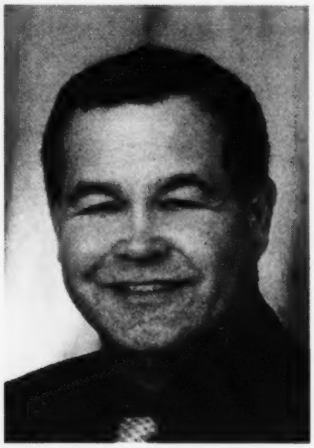
REPORT OF ACTIVITIES 2007



A message from the Minister:

Manitoba means business and with over $2 billion in mineral production for 2006, *mining means big business* for our provincial economy. It also means jobs, economic development and prosperity for many Manitoba communities.

We recognize the industry's importance and we know how to support and strengthen it to attract companies that will help us explore and develop our mineral wealth. Simply put, 'Manitoba gets it' when it comes to mining. Mining companies worldwide also recognize that Manitoba gets it — they ranked us FIRST in the world for mineral policies in the 2006 Fraser Institute survey.

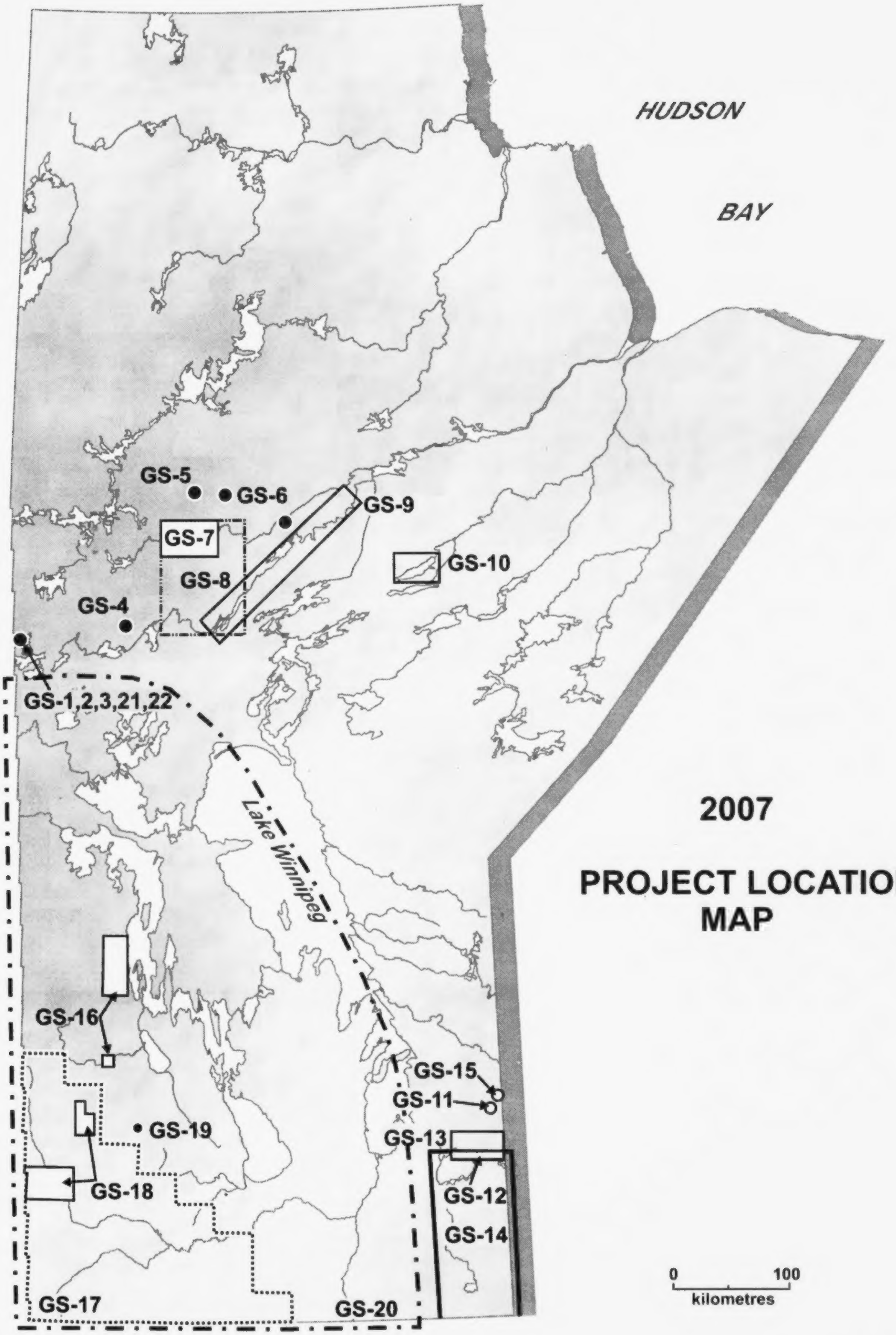
Our policies balance sound business practices with responsible government, providing the solid framework that's essential for successful mineral investment ventures. From these policies we've developed attractive financial incentives, a stable and effective regulatory framework and a comprehensive geoscience knowledge-base to support exploration and mining in the province.

The annual *Report of Activities* is just one of the exploration tools we produce to assist your industry. It summarizes the Manitoba Geological Survey's geoscience investigations from the past year, including new field programs, new digital initiatives, and collaborative ventures with the federal government, universities, and the mineral exploration industry.

The *Report of Activities* is released at our Manitoba Mining and Minerals Convention where delegates can obtain a complimentary copy in print and in digital format on CD. We also make the report available on our website for free download and for purchase through our Publication Sales to ensure that the latest on Manitoba's geology and mineral resources is readily accessible to everyone.

I invite you to explore Manitoba — where your success is our business.

Honourable Jim Rondeau
Minister of Science, Technology, Energy and Mines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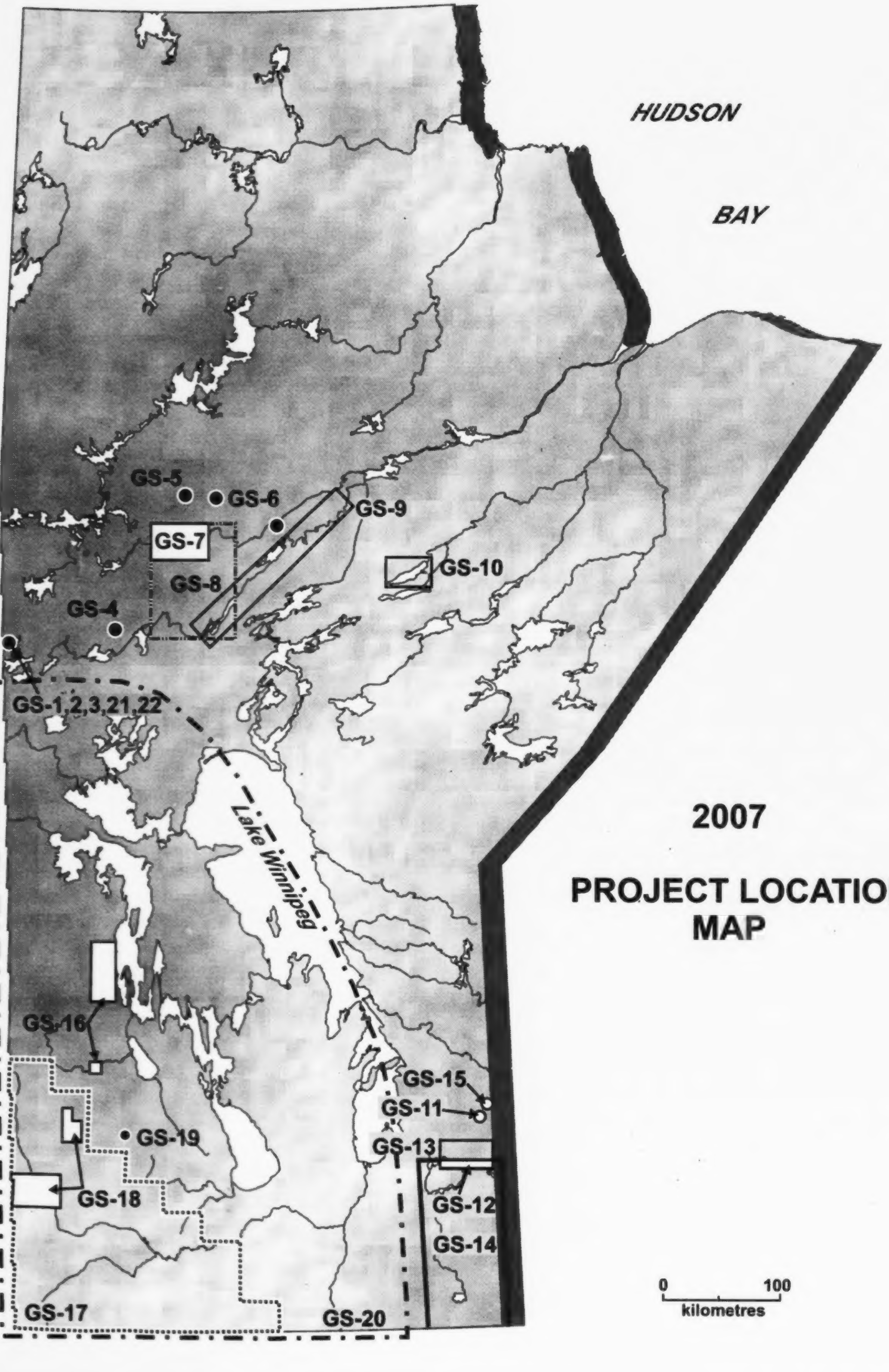
PROJECT LOCATION MAP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Introduction

In 2007, the Manitoba Geological Survey (MGS) continued multiyear programs in the northern Superior Province, the Paleoproterozoic Flin Flon Belt, the eastern Kisseynew Domain and Thompson Nickel Belt (TNB), and the Bissett and Bird River regions of southeastern Manitoba. Phanerozoic investigations focused on posting new Williston Basin Targeted Geoscience Initiative (TGI) content to the project's website, expanding the study of the Devonian Three Forks Formation and completing the Surficial Geology Compilation Map Series.

New field projects were initiated in

- the northern Superior Province, at Utik Lake, as the second year of a multiyear project aimed at updating the bedrock mapping database for greenstone belts in the region; and
- the Notigi Lake area, as a contribution to the Targeted Geoscience Initiative III (TGI-3).

Targeted Geoscience Initiative

A significant portion of MGS work in 2007 was conducted as part of the Targeted Geoscience Initiative (TGI). This initiative provides a vehicle to partner with the Geological Survey of Canada (GSC) on priority projects aimed at improving the economic sustainability of mining towns in northern Manitoba. The current TGI, announced in the February 2005 federal budget, is the third in a series of such initiatives since 2000. Federal funding for TGI-3 is $25 million (nationally), to be spent over a five-year period that started April 1, 2005.

The TGI-3 Flin Flon project is an integrated, multidisciplinary geoscience study to aid in the discovery of new reserves of base metals in established mining communities of west-central Manitoba and east-central Saskatchewan. The project has been developed through joint provincial-federal-industry consultation and is delivered as a fully integrated partnership that includes the minerals industry, researchers from Canadian and American universities, and geologists from the MGS, the Saskatchewan Geological Survey (SGS) and the GSC.

Individual MGS projects associated with TGI-3 are described separately in subsequent sections. Those components of the Flin Flon project funded by the GSC that were conducted in or adjacent to Manitoba and are not reported in this volume include

- collection and subsequent analysis of approximately 45 km of two-dimensional (2-D) seismic profile data at Flin Flon; in addition, Hudson Bay Exploration and Development Co. Ltd. has separately contracted additional 2-D profiles and a 3-D seismic survey at Flin Flon;
- a high-resolution aeromagnetic survey in the eastern Kisseynew Domain area, building on a 2006 survey on the west flank of the Thompson Nickel Belt;
- Quaternary mapping and sampling in the Sherridon, Snow Lake and eastern Kisseynew Domain areas;
- borehole-geophysical-data processing (rock property data) as an input into the seismic studies subproject; and
- detailed mapping at Flin Flon by researchers and graduate students at Laurentian University.

Precambrian mapping

Flin Flon–Snow Lake greenstone belt

As part of the MGS contribution to TGI-3, metavolcanic rocks in the Flin Flon area were mapped at 1:5000 scale, including (in Manitoba) the northern part of Schist Lake–Mandy Road area, the Hidden Lake syncline area and part of the Hook Lake Block (Simard and Creaser, GS-1). Using a combination of detailed volcanic facies analysis, structural mapping and geochemical characterization of each unit in the area, this mapping has extended the recently established Flin Flon–Callinan–Triple 7 mine stratigraphy from the Flin Flon mine area south to Schist Lake. Uncertainties remain because the proximal volcanic arc environments characteristic of Flin Flon are highly complex due to multiple volcanic centres, local subsidence structures and the episodic nature of volcanism. Work is currently underway to better understand the structural evolution of the immediate Flin Flon area and to define the timing and geometry of the multiple deformation events and their effect on the distribution of mine stratigraphy. New and previous mapping in the Flin Flon area has been compiled and assembled into a 1:10 000 scale cross-border map to be published as part of the TGI-3 project.

As a contribution to the Flin Flon 1:10 000 compilation, detailed mapping was also conducted in the Hook Lake Block (Kremer and Simard, GS-2). This area contains a comparatively unique volcanic and volcaniclastic stratigraphy with respect to the Flin Flon Block to the west. The mapping has highlighted many similarities between Hook Lake Block rocks and those of the neighbouring Flin Flon Block: both contain volcanic stratigraphy displaying significant subsidence or basin structures, with associated felsic volcanism and VMS-type mineralization. However, a direct correlation between the stratigraphy of the Hook Lake Block and that of the Flin Flon Block is premature.

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Laurentian University researchers H. Gibson and B. Lafrance, together with graduate students E. Cole, D. Lewis and M. DeWolfe, continued detailed mapping in the footwall and hangingwall rocks of the Flin Flon, Callinan and Triple 7 deposits. A two-year research project to characterize and describe the Schist Lake–Mandy Road volcanogenic massive sulphide deposits and their hostrocks was started in 2007 by one of the Laurentian graduate students (Cole and Gibson, GS-3). The Schist Lake and Mandy deposits were the first to be mined in the Flin Flon area, but their stratigraphic relationship to the other Flin Flon Cu-Zn deposits is still not established. Preliminary results suggest that the Schist Lake orebody and host strata were dismembered by a shear zone.

East Kisseynew–Superior Boundary Zone–Thompson Nickel Belt

The MGS and partners in the GSC continued a multiyear program, within TGI-3, aimed at defining the geographic extent of TNB-type inliers within what is currently mapped as younger Burntwood Group metaturbidite rocks in the northeastern Kisseynew Domain. Exciting and unexpected results from detailed mapping, isotopic and geochronological investigations have shown that Archean basement, together with an autochthonous cover sequence, occur in this part of the Kisseynew Domain. The origin, structure and extent of these older rocks in the predominantly greywacke-derived migmatite of the northeastern Kisseynew Domain are still poorly understood. This work has clear implications for nickel exploration, opening up new areas for consideration that would have been disregarded only five years ago.

New mapping was undertaken in 2007 at Notigi Lake, on the north flank of the Kisseynew Domain northwest of Thompson (Murphy and Zwanzig, GS-5). The study area represents an example of the stratigraphic and structural relationships of the Paleoproterozoic Burntwood and Sickle groups, as well as a prominent amphibolite that is reinterpreted as volcanic in origin and may mark a regional crustal suture. Previous geological investigations have been updated using new structural data and analysis, as well as lithological subdivision of the Sickle Group. The structural style of the Notigi Lake area may serve as a guide to determine the structural style and 3-D extent of the Archean and Ospwagan-like rocks in the Kisseynew Domain.

Fieldwork was conducted during the summers of 2006 and 2007 in the Kawaweyak Lake area of the northeasternmost Kisseynew Domain to determine the provenance of potentially Ospwagan Group–equivalent rocks. A sample of semipelite has yielded a Nd model age inconsistent with an affinity for the Ospwagan Group but similar to either the juvenile Paleoproterozoic Burntwood Group or an assemblage of amphibolite and siliciclastic rocks that generally overlies the Burntwood Group.

Work led by the GSC in the northeastern Kisseynew Domain (Percival et al., GS-7) as part of the TGI-3 project aims to delimit the distribution of Archean basement and Ospwagan Group–like supracrustal rocks within what is currently depicted as Burntwood Group metasedimentary rocks. The occurrence of pre-Burntwood intrusions as far west as Atik Lake suggests that basement complex rocks occur widely beneath the region. Although these rocks could potentially host Thompson-type deposits, their prospectivity would be limited except near exposed structural culminations.

Geochronological results from proposed Archean inliers within the Kisseynew Domain (Rayner and Percival, GS-8) provide further evidence of Archean basement rocks underlying the northeastern quadrant of the Kisseynew Domain. Although a definitive correlation has not been made between Ospwagan-type supracrustal rocks within the Kisseynew Domain and Ospwagan Group rocks within the TNB, the potential for Thompson-type nickel mineralization is still present. The lithological association of basement, supracrustal rocks including iron formation, and mafic-ultramafic sills in the Wuskwatim Lake–Burntwood River area and possibly the Tullibee–Neuls lakes area is similar with those observed in the TNB.

Within the Thompson Nickel Belt proper, the objective of a continuing Ph.D. study on regional metamorphism is to better understand the tectonic evolution of the belt (Couëslan et al., GS-9). Documenting the Ospwagan Group at various metamorphic grades will assist in the identification of these prospective rocks during exploration programs, especially in portions of the belt that have been subjected to higher grades of metamorphism. The local grade of regional metamorphism may also significantly affect the mobilization of orebodies through solid-state, hydrothermal and anatectic processes.

Northern Superior Province

An Archean mafic metavolcanic–dominated greenstone belt at Utik Lake in central Manitoba was mapped and studied in detail (Böhm et al., GS-10) to determine the nature, age and composition of the supracrustal rocks. Work also included an analysis of the kinematics and structural evolution of the Utik Lake greenstone belt, and an assessment of the potential of the area to host volcanogenic massive sulphide and gold deposits. Together with 2006 mapping in the nearby Bear Lake area, this study will provide an improved geological context and regional framework for base- and precious-metal exploration in the northern Superior Province.

Bird River Belt

In 2005, the MGS initiated a government-industry-university partnership in the Neoarchean Bird River Belt of southeastern Manitoba. Partners in the initiative include the MGS, researchers and graduate students at the University of Waterloo (partially funded by Gossan Resources Limited, Mustang Minerals Corp., Tantalum Mining Corporation of Canada Limited [Tanco], the university and the Natural Sciences and Engineering Research Council of Canada). The group is undertaking mapping, structural analysis and geochronological investigations in order to better understand both the evolution of the Bird River Belt and the setting of the various deposit types, and to support the exploration programs that are currently underway in the area. Work in 2007 completed the three-year project; M.Sc. students P. Kremer and C. Mealin finished their fieldwork in 2006.

Field investigations in 2007 by University of Waterloo postdoctoral fellow M. Duguet (GS-13) have highlighted the kinematic pattern of a major shear zone separating the English River Subprovince from the Bird River greenstone belt. New geochronological data on the Maskwa Batholith demonstrate that it should be considered an independent microcontinent that split off during a back-arc spreading event. Occurrences of Ni–Cu–platinum group element (PGE) mineralization in mafic-ultramafic bodies are associated with this event and are found on both sides of the Maskwa Batholith (i.e., Bird River Sill and Maskwa-Dumbarton mines to the south, and Mayville Formation to the north).

Regional and detailed stratigraphic mapping, geochemical and geochronological investigations within the Bird River greenstone belt have resulted in a revised stratigraphic framework (Gilbert, GS-12) defining predominant arc-type rocks that are tectonically distinct from flanking, older, back-arc–type basaltic sequences. The basalt sequence is intruded by the Bird River Sill. Mineralization associated with the metavolcanic rocks includes a variety of occurrences located either at lithological contacts or within stratigraphic members such as felsic volcanic rocks in the arc succession and in basalt of the back-arc succession.

Mineral deposit studies

Snow Lake

A metallogenic and metamorphic study of selected gold-bearing deposits from Snow Lake and the southern flank of the Kisseynew Domain by McGill University Ph.D. candidate S. Gagné (GS-4) is supported by the MGS and the GSC. Investigation of sulphide-gold mineralization will provide new constraints on the timing of mineralization and a better understanding of the mineralogical and compositional consequences of mid-amphibolite–facies metamorphism on sulphide-dominated ore. The study will also increase knowledge of sulphide-silicate-oxide interaction during prograde metamorphism and help to delineate the effects of the sulphidization and oxidation halo on altered wallrock.

Southeastern Manitoba

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Phanerozoic investigations

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Williston Basin Targeted Geoscience Initiative

The Williston Basin TGI-2 project has shown that interprovincial subsurface correlations are invaluable

Laurentian University researchers H. Gibson and B. Lafrance, together with graduate students E. Cole, D. Lewis and M. DeWolfe, continued detailed mapping in the footwall and hangingwall rocks of the Flin Flon, Callinan and Triple 7 deposits. A two-year research project to characterize and describe the Schist Lake–Mandy Road volcanogenic massive sulphide deposits and their hostrocks was started in 2007 by one of the Laurentian graduate students (Cole and Gibson, GS-3). The Schist Lake and Mandy deposits were the first to be mined in the Flin Flon area, but their stratigraphic relationship to the other Flin Flon Cu-Zn deposits is still not established. Preliminary results suggest that the Schist Lake orebody and host strata were dismembered by a shear zone.

East Kisseynew–Superior Boundary Zone–Thompson Nickel Belt

The MGS and partners in the GSC continued a multiyear program, within TGI-3, aimed at defining the geographic extent of TNB-type inliers within what is currently mapped as younger Burntwood Group metaturbidite rocks in the northeastern Kisseynew Domain. Exciting and unexpected results from detailed mapping, isotopic and geochronological investigations have shown that Archean basement, together with an autochthonous cover sequence, occur in this part of the Kisseynew Domain. The origin, structure and extent of these older rocks in the predominantly greywacke-derived migmatite of the northeastern Kisseynew Domain are still poorly understood. This work has clear implications for nickel exploration, opening up new areas for consideration that would have been disregarded only five years ago.

New mapping was undertaken in 2007 at Notigi Lake, on the north flank of the Kisseynew Domain northwest of Thompson (Murphy and Zwanzig, GS-5). The study area represents an example of the stratigraphic and structural relationships of the Paleoproterozoic Burntwood and Sickle groups, as well as a prominent amphibolite that is reinterpreted as volcanic in origin and may mark a regional crustal suture. Previous geological investigations have been updated using new structural data and analysis, as well as lithological subdivision of the Sickle Group. The structural style of the Notigi Lake area may serve as a guide to determine the structural style and 3-D extent of the Archean and Ospwagan-like rocks in the Kisseynew Domain.

Fieldwork was conducted during the summers of 2006 and 2007 in the Kawaweyak Lake area of the northeasternmost Kisseynew Domain to determine the provenance of potentially Ospwagan Group–equivalent rocks. A sample of semipelite has yielded a Nd model age inconsistent with an affinity for the Ospwagan Group but similar to either the juvenile Paleoproterozoic Burntwood Group or an assemblage of amphibolite and siliciclastic rocks that generally overlies the Burntwood Group.

Work led by the GSC in the northeastern Kisseynew Domain (Percival et al., GS-7) as part of the TGI-3 project aims to delimit the distribution of Archean basement and Ospwagan Group–like supracrustal rocks within what is currently depicted as Burntwood Group metasedimentary rocks. The occurrence of pre-Burntwood intrusions as far west as Atik Lake suggests that basement complex rocks occur widely beneath the region. Although these rocks could potentially host Thompson-type deposits, their prospectivity would be limited except near exposed structural culminations.

Geochronological results from proposed Archean inliers within the Kisseynew Domain (Rayner and Percival, GS-8) provide further evidence of Archean basement rocks underlying the northeastern quadrant of the Kisseynew Domain. Although a definitive correlation has not been made between Ospwagan-type supracrustal rocks within the Kisseynew Domain and Ospwagan Group rocks within the TNB, the potential for Thompson-type nickel mineralization is still present. The lithological association of basement, supracrustal rocks including iron formation, and mafic-ultramafic sills in the Wuskwatim Lake–Burntwood River area and possibly the Tullibee–Neuls lakes area is similar with those observed in the TNB.

Within the Thompson Nickel Belt proper, the objective of a continuing Ph.D. study on regional metamorphism is to better understand the tectonic evolution of the belt (Couëslan et al., GS-9). Documenting the Ospwagan Group at various metamorphic grades will assist in the identification of these prospective rocks during exploration programs, especially in portions of the belt that have been subjected to higher grades of metamorphism. The local grade of regional metamorphism may also significantly affect the mobilization of orebodies through solid-state, hydrothermal and anatectic processes.

Northern Superior Province

An Archean mafic metavolcanic–dominated greenstone belt at Utik Lake in central Manitoba was mapped and studied in detail (Böhm et al., GS-10) to determine the nature, age and composition of the supracrustal rocks. Work also included an analysis of the kinematics and structural evolution of the Utik Lake greenstone belt, and an assessment of the potential of the area to host volcanogenic massive sulphide and gold deposits. Together with 2006 mapping in the nearby Bear Lake area, this study will provide an improved geological context and regional framework for base- and precious-metal exploration in the northern Superior Province.

Bird River Belt

In 2005, the MGS initiated a government-industry-university partnership in the Neoarchean Bird River Belt of southeastern Manitoba. Partners in the initiative include the MGS, researchers and graduate students at the University of Waterloo (partially funded by Gossan Resources Limited, Mustang Minerals Corp., Tantalum Mining Corporation of Canada Limited [Tanco], the university and the Natural Sciences and Engineering Research Council of Canada). The group is undertaking mapping, structural analysis and geochronological investigations in order to better understand both the evolution of the Bird River Belt and the setting of the various deposit types, and to support the exploration programs that are currently underway in the area. Work in 2007 completed the three-year project; M.Sc. students P. Kremer and C. Mealin finished their fieldwork in 2006.

Field investigations in 2007 by University of Waterloo postdoctoral fellow M. Duguet (GS-13) have highlighted the kinematic pattern of a major shear zone separating the English River Subprovince from the Bird River greenstone belt. New geochronological data on the Maskwa Batholith demonstrate that it should be considered an independent microcontinent that split off during a back-arc spreading event. Occurrences of Ni–Cu–platinum group element (PGE) mineralization in mafic-ultramafic bodies are associated with this event and are found on both sides of the Maskwa Batholith (i.e., Bird River Sill and Maskwa-Dumbarton mines to the south, and Mayville Formation to the north).

Regional and detailed stratigraphic mapping, geochemical and geochronological investigations within the Bird River greenstone belt have resulted in a revised stratigraphic framework (Gilbert, GS-12) defining predominant arc-type rocks that are tectonically distinct from flanking, older, back-arc–type basaltic sequences. The basalt sequence is intruded by the Bird River Sill. Mineralization associated with the metavolcanic rocks includes a variety of occurrences located either at lithological contacts or within stratigraphic members such as felsic volcanic rocks in the arc succession and in basalt of the back-arc succession.

Mineral deposit studies

Snow Lake

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Williston Basin Targeted Geoscience Initiative

The Williston Basin TGI-2 project has shown that interprovincial subsurface correlations are invaluable and represent a significant accomplishment. This is best demonstrated in the new stratigraphic correlation chart and database of the study area that are now available for viewing on the website (http://www.gov.mb.ca/iedm/mrd/geo/willistontgi/index.html). This information, together with the detailed crossborder Mesozoic correlations, will be of assistance to the petroleum exploration industry in southwestern Manitoba.

Phanerozoic stratigraphy

Three coreholes were drilled in the 2007 Stratigraphic Corehole Drilling Program (Bamburak, GS-16). One hole near Duck Bay, west of Lake Winnipegosis, penetrated what is interpreted as hydrothermally altered dolomite within the upper part of the Silurian Interlake Group, beneath the Devonian Ashern Formation. This discovery, if confirmed, would be significant because it would indicate that hydrothermal fluids have flowed through and locally altered the Paleozoic stratigraphic sequence, increasing porosity and permeability. The leached limestone and dolomite could potentially host Mississippi Valley–type Pb-Zn mineralization, explaining the sulphide mineralization found, for example, near Pemmican Island in the north basin of Lake Winnipegosis.

The discovery of the new, conventional-oil Sinclair Field in southwestern Manitoba has substantially increased Manitoba's oil reserves and coincided with the TGI crossborder correlations. New work was also conducted on the Devonian Three Forks Formation in southwestern Manitoba (Nicolas, GS-17). The Three Forks Formation hosts the Sinclair Field, with proven and probable reserves estimated at 6.8 million m^3. A number of new exploration targets were identified in this study, northward and eastward of the Sinclair Field. Further study of the Devonian Three Forks Formation in Manitoba may see an expansion of the play beyond the current boundaries of the Sinclair Field.

Industrial minerals investigations

Industrial minerals potential was investigated in the Rural Municipalities of Miniota, Archie and Rossburn in southwestern Manitoba (Bamburak, GS-18). Undeveloped deposits of Souris-type gravel, swelling sodium bentonite, potash and sodium chlorate, or manganese are present in some of the rural municipalities and would help to diversify their economic base.

Surficial Geology Compilation Map Series

The Surficial Geology Compilation Map Series (SGCMS) has been completed and was released on November 15, 2007 on DVD (second edition) and as a hard copy, 1:1 000 000 scale surficial geology map. The SGCMS provides seamless, province-wide coverage of all the most current and detailed surficial geology available. These data are useful for applications such as groundwater protection, land management and mineral exploration.

The final 1:1 000 000 scale compilation is a unique, two-sided, full-colour map that supersedes Geoscientific Map 81-1, released in 1981. The front of the new map contains 1) hill-shaded surficial geology polygons; 2) major landforms, including glacial ice-flow direction; and 3) a brief description of Manitoba's landscape. The back of the map contains 1) an innovative, graphic description of map units, including images and diagrams to define each unit in nonscientific terms; 2) an index map to locate the images; 3) a paleogeographic reconstruction of late glacial events; 4) diagrams depicting the effect of isostatic rebound on the Tyrrell Sea and lakes Winnipeg and Manitoba; and 5) a 3-D block diagram. All SGCMS products are also available for download from http://www.gov.mb.ca/iedm/mrd/geo/gis/surfgeomap.html in PDF and shapefile formats.

Aggregate resources

The Rural Municipality of Park was mapped this year to update aggregate information for land-use planning (Groom, GS-19). The nature of the landscape and proximity to Riding Mountain National Park have resulted in increased recreational development, which has in turn put increasing land-use pressure on aggregate deposits in some parts of the municipality. Field results suggest that the volume of aggregate in the areas of the nearby active pits is more than adequate to meet the current and projected needs, but land-use planning decisions need to take these important resources into account so they can continue to be utilized.

Other projects

Hydrological dynamics in the Winnipeg River basin

The Winnipeg River in northwestern Ontario provides nearly half of the total flow into Lake Winnipeg and the Nelson River, and is the most important component of the hydroelectric system that generates power for Manitoba. A continuing study by S. St. George (GS-14) uses a network of 54 tree-ring records to estimate changes in summer climate within the Winnipeg River basin since AD 1783. The tree-ring record indicates that summer droughts were more persistent in the 19th and late 18th centuries, but there is no evidence that drought was more extreme prior to the onset of direct monitoring. This research program has demonstrated that, unlike most regional rivers, flow in the Winnipeg River system increased during the 20th century, with most of the gains occurring between 1920 and 1960. For a longer perspective, tree-ring records from the Winnipeg River basin and the broader Prairies region have been used to estimate drought conditions in the Manitoba Hydro watershed during the last several hundred years.

Revegetation of tailings at the Gunnar minesite

University of Manitoba researchers continued with a program investigating the revegetation of mine tailings (Renault et al., GS-15). A small-scale field experiment was designed in 2007 to test the effects on plant establishment and growth of rototilling, fertilizing, microbial inoculation and amending Gunnar tailings with paper-mill sludge. Research oriented towards using readily available amendments, such as paper-mill sludge, to increase revegetation success on such sites would benefit the paper-mill and mining industries, as well as the government and future land users.

Core storage facilities

Manitoba's Mineral Resources Division has been storing Precambrian drillcore, obtained primarily from exploration drilling, since the early 1970s (GS-22). Since that time, the Manitoba government has created a substantial repository of drillcore at five locations throughout the province (Thompson, Flin Flon, Lynn Lake, The Pas, and Winnipeg).

Compilation and partnerships

The Manitoba Geological Survey is engaged in many partnered initiatives, including contributions from the federal government, the mineral industry and several Canadian universities. Partnerships added approximately $1.4 million to geoscience programming in Manitoba for 2007–2008, and represent significant leverage of the MGS geoscience budget. The projects facilitate the training of future geoscience professionals, including in 2007 one postdoctoral fellow, two Ph.D. candidates and one M.Sc. candidate. Primary focuses for partnerships in 2007 were the Flin Flon TGI-3 project and the Bird River suite of projects.

Geoscience Information Services

The Geoscience Information Services section continues to support the operation of the Geological Survey's research activities by providing data management, GIS and graphic production services.

During 2006, more than 200 isopach and structure contour maps were produced for the Williston Basin TGI-2 project, using a standardized database combining Manitoba and Saskatchewan data. Work continued through 2007 on finalizing databases and producing maps for the upper parts of the stratigraphic section.

Recompilation and updating of existing Bedrock Geology Compilation Maps resulted in the production of a seamless 1:250 000 scale digital geological base map for Manitoba, with approximately two-thirds of the province now compiled and edge-matched.

Work on the Thompson Nickel Belt project continued in 2007, with the focus being production of a final printed map series.

The compilation of open file company geophysical datasets has focused on expanding the number of datasets and converting the data presentations to standard format, with particular emphasis on converting data to standard projection and datum.

Geoscience Information Services has devoted considerable effort to supporting ongoing compilation at 1:5000 and 1:2000 scales in the Flin Flon Belt.

Client services and outreach

In 2006–2007, the MGS published two geoscientific reports, including the annual Report of Activities, thirteen maps, one database and two data repository items. In response to client needs, the majority of the publications were released as hard copy, CD-ROM, or DVD for purchase through Publication Sales, and in electronic format for free download via the Web.

Manitoba Geological Survey mineral-education outreach initiatives included the Manitoba Mining and Minerals Convention (MMMC) Schools Program, National Engineering and Geoscience Week, Earth Science Week and Provincial Mining Week. Twenty-seven students from Cross Lake First Nation in northern Manitoba made the trip to Winnipeg to take part in the 2006 MMMC mineral education activities. Provincial Mining Week offered free, hands-on activities developed to complement the Earth Sciences curriculum and increase public awareness of the importance of Manitoba's mineral resources and mining industry. Despite inclement weather, the outdoor event drew more than 2500 visitors. In August, the MGS partnered with the Manitoba Children's Museum for the first time to help celebrate the museum's Earth Science Week; 158 people participated in the MGS-sponsored activities.

The third annual Aboriginal Mining Workshop was held as part of the November 2006 Manitoba Mining and Minerals Convention. Eighty participants met to discuss mineral exploration and development opportunities, including training, employment, business ventures and social initiatives.

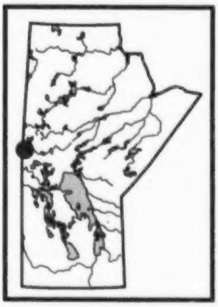
Survey staff delivered mining and geology presentations to Aboriginal communities at Fox Lake Cree Nation, Northlands First Nation and the Nelson House Resource Management Board, as well as Wolseley School, the Winnipeg Rock and Mineral Club and the Mineral Society of Manitoba. In addition, staff attended such Aboriginal conferences as Vision Quest and the Canadian Aboriginal Minerals Association.

Acknowledgments

The careful work of MGS geologists, lab technicians, expeditors, students, cartographers, publication staff and administration went into the production of the Report of Activities 2007. Bob Davie, Joan Dawson and Nicole Barlow of RnD Technical carefully performed technical editing and Craig Steffano completed the final layout for publication.

GS-1 Implications of new geological mapping, geochemistry and Sm-Nd isotope data, Flin Flon area, Manitoba (part of NTS 63K12)

by R-L. Simard and R.A. Creaser[1]



Simard, R-L and Creaser, R.A. 2007: Implications of new geological mapping, geochemistry and Sm-Nd isotope data, Flin Flon area, Manitoba (part of NTS 63K12); *in* Report of Activities 2007, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 7–20.

Summary

Over the last two years, the rocks of the Flin Flon area have been the focus of a new 1:5000 scale bedrock mapping campaign aiming at the production of a new 1:10 000 scale stratigraphically coherent cross-border geological map, as part of the federal Targeted Geoscience Initiative (TGI-3). Using a combination of detailed volcanic facies analysis, structural mapping and thorough geochemical characterization of each unit in the area, this mapping campaign has allowed the recently established Flin Flon–Callinan–Triple 7 mine stratigraphy to be extended away from the main mines area south to Schist Lake.

Rocks west of the Mandy Road Fault in the Schist Lake–Mandy mines area, approximately 5 km south of Flin Flon, are mainly juvenile tholeiitic, aphyric and pyroxene-plagioclase–phyric basaltic flows with a lesser amount of plagioclase-crystal–rich heterolithic mafic breccia. These rocks are most similar to those in the Hidden and Louis formation rocks, the hangingwall rocks of the Flin Flon–Callinan–Triple 7 mine. Rocks east of the Mandy Road fault, however, are heterolithic mafic breccia (not plagioclase-crystal rich) with minor aphyric basaltic flows and host the Schist Lake and Mandy volcanogenic massive sulphide (VMS) deposits. These rocks appear to be different from both the footwall and the hangingwall rocks of the Flin Flon–Callinan–Triple 7 mines.

Mapping of the main structural elements in the Hidden Lake area, just south of the CN Rail line in the main Flin Flon–Callinan–Triple 7 mine stratigraphy, has highlighted a need for further work in that domain. Although individual structures such as the Hidden Lake syncline, the Railway Faults, the Missi wedge structure and the Ross Lake Fault can be readily documented, their relative timing is not satisfactorily resolved.

Introduction

The Flin Flon area of the Paleoproterozoic Flin Flon Belt is well known for its volcanogenic massive sulphide (VMS) deposits. Three active (Callinan, Triple 7 and Trout Lake) and three past-producing (Flin Flon, Mandy and Schist Lake) VMS mines occur in the immediate vicinity of the town of Flin Flon, which makes this area one of the most productive base-metal regions in Canada.

With the intent of stimulating private-sector resource exploration in areas of high base-metal potential in established mining communities, the Government of Canada launched a new five-year Targeted Geoscience Initiative (TGI-3) in 2005. As part of this initiative, the Manitoba Geological Survey, in collaboration with the Saskatchewan Geological Survey, the Geological Survey of Canada and researchers from Laurentian University, is participating in the production of a new 1:10 000 scale coherent stratigraphic cross-border geological map of the Flin Flon area.

This report summarizes observations and data collected during the final twelve-week field program of 1:5000 scale bedrock geological mapping in the Flin Flon area during the summer of 2007. In addition, it includes new geochemical and isotopic results from last year's mapping in the area. The field and analytical studies in this area are intended to characterize and differentiate the various volcanic sequences, provide constraints on their distribution and assess their stratigraphic position relative to those hosting the VMS deposits at Flin Flon.

Regional setting

The Paleoproterozoic Flin Flon Belt is part of the Reindeer Zone of the Trans-Hudson Orogen (Figure GS-1-1). The Flin Flon Belt consists of a series of tectonostratigraphic assemblages (juvenile arc, juvenile ocean-floor backarc, ocean plateau, oceanic-island basalt and evolved plutonic arc) that range in age from 1.92 to 1.87 Ga (Syme et al., 1999). All of the VMS deposits mined to date in the Flin Flon area are associated with the 1.9 Ga juvenile Flin Flon arc assemblage (Syme et al., 1999).

Volcanic rocks of the Flin Flon arc assemblage mainly consist of tholeiitic subaqueous pillowed basalt and basaltic andesite, with lesser amounts of heterolithic mafic breccia and mafic and felsic volcaniclastic rocks, and minor dacitic to rhyolitic flows (Bailes and Syme, 1989). Within the dominantly mafic volcanic complex at Flin Flon, the VMS deposits are spatially linked to felsic volcanic units that occur in synvolcanic collapse structures and calderas (Bailes and Syme, 1989; Syme and Bailes, 1993; Figure GS-1-2).

Bedrock geology of the Flin Flon area

Exposure in the Flin Flon area is exceptional, with

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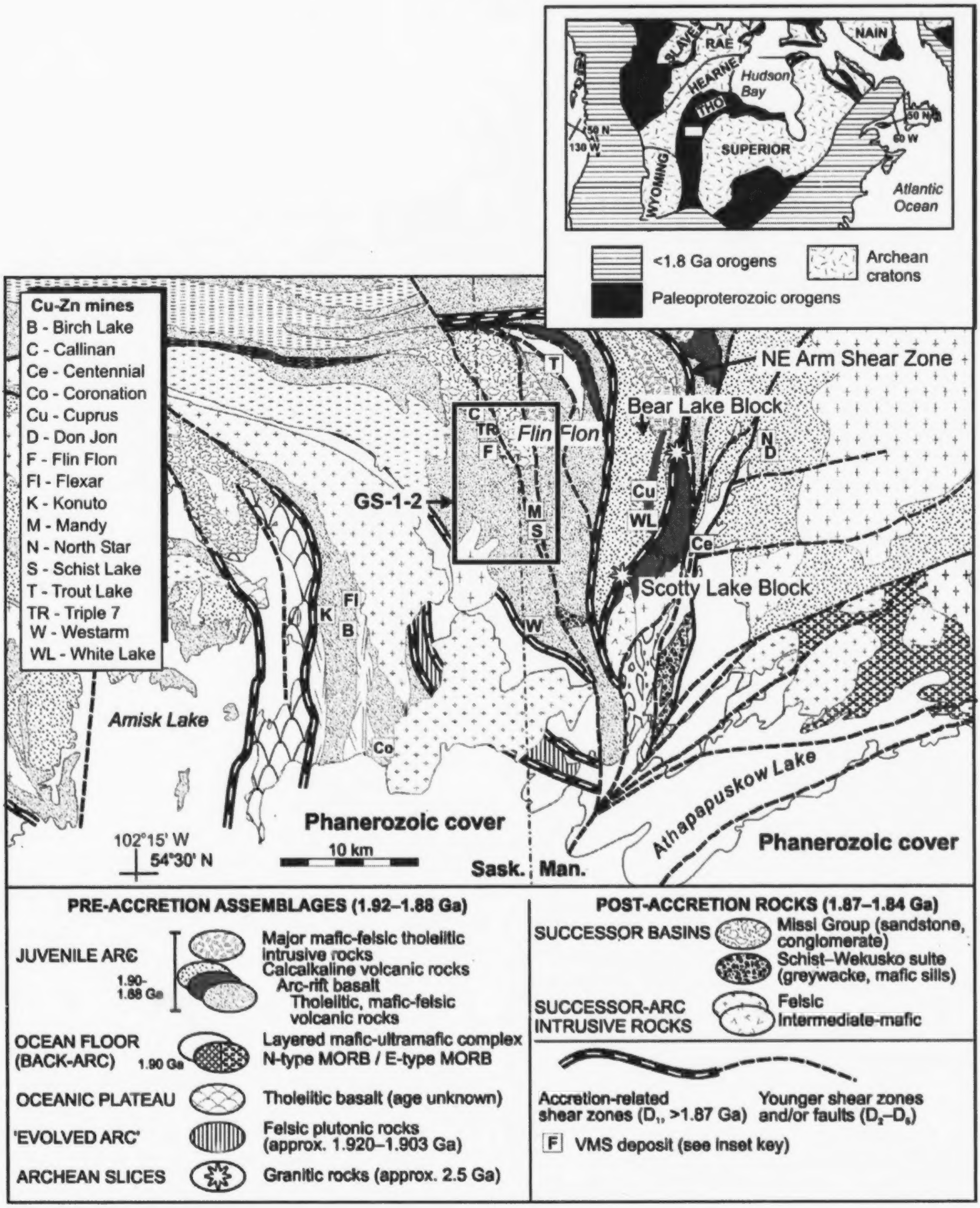
NAIN
RAE
SLAVE
HEARNE
Hudson Bay
THO
50 N
130 W
50 N
60 W
SUPERIOR
WYOMING
Atlantic Ocean
<1.8 Ga orogens
Archean cratons
Paleoproterozoic orogens
Cu-Zn mines
B - Birch Lake
C - Callinan
Ce - Centennial
Co - Coronation
Cu - Cuprus
D - Don Jon
F - Flin Flon
Fl - Flexar
K - Konuto
M - Mandy
N - North Star
S - Schist Lake
T - Trout Lake
TR - Triple 7
W - Westarm
WL - White Lake
NE Arm Shear Zone
Bear Lake Block
Flin Flon
GS-1-2
Scotty Lake Block
Amisk Lake
Athapapuskow Lake
Phanerozoic cover
Phanerozoic cover
102°15' W
54°30' N
10 km
Sask.
Man.
PRE-ACCRETION ASSEMBLAGES (1.92–1.88 Ga)
JUVENILE ARC
1.90-1.88 Ga
Major mafic-felsic tholeiitic intrusive rocks
Calcalkaline volcanic rocks
Arc-rift basalt
Tholeiitic, mafic-felsic volcanic rocks
OCEAN FLOOR (BACK-ARC)
1.90 Ga
Layered mafic-ultramafic complex
N-type MORB / E-type MORB
OCEANIC PLATEAU
Tholeiitic basalt (age unknown)
'EVOLVED ARC'
Felsic plutonic rocks (approx. 1.920–1.903 Ga)
ARCHEAN SLICES
Granitic rocks (approx. 2.5 Ga)
POST-ACCRETION ROCKS (1.87–1.84 Ga)
SUCCESSOR BASINS
Missi Group (sandstone, conglomerate)
Schist–Wekusko suite (greywacke, mafic sills)
SUCCESSOR-ARC INTRUSIVE ROCKS
Felsic
Intermediate-mafic
Accretion-related shear zones (D1, >1.87 Ga)
Younger shear zones and/or faults (D2–D5)
F VMS deposit (see inset key)

Figure GS-1-1: *Geology of the Flin Flon Belt, showing locations of known volcanogenic massive sulphide (VMS) deposits (modified from Syme et al., 1999); box indicates the area covered by Figure GS-1-2; inset map shows the location of the Flin Flon Belt within the Trans-Hudson Orogen (THO).*

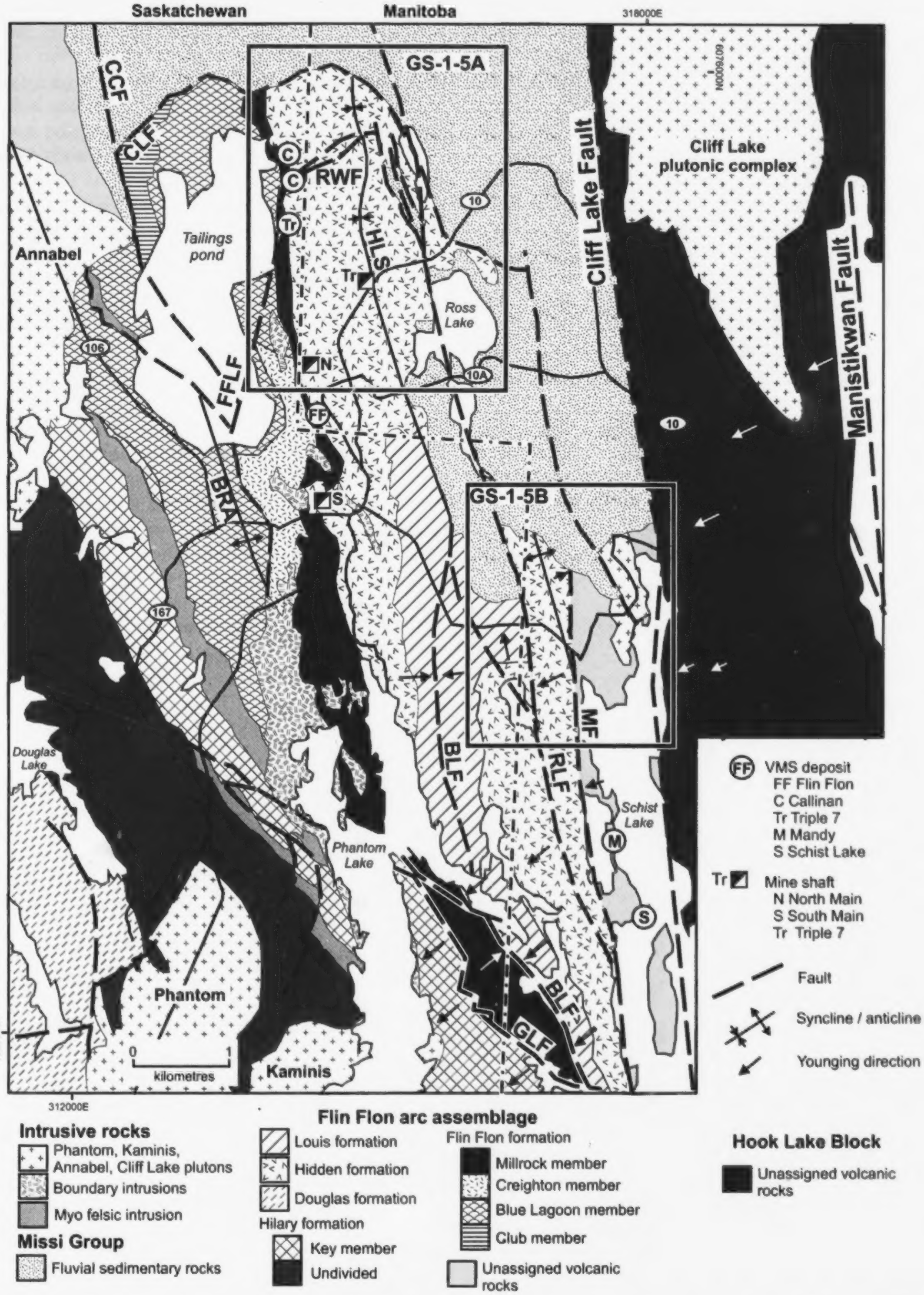
Saskatchewan
Manitoba
318000E
6076000N
GS-1-5A
CCF
CLF
C
C
RWF
Tr
HLS
10
Tailings pond
Annabel
Tr
Ross Lake
Cliff Lake Fault
Cliff Lake plutonic complex
Manistikwan Fault
106
FFLF
N
10A
FF
10
BRA
S
GS-1-5B
167
Douglas Lake
BLF
MF
RLF
Schist Lake
M
Phantom Lake
S
BLF
GLF
Phantom
0
1
kilometres
Kaminis
6066000N
312000E
VMS deposit
FF Flin Flon
C Callinan
Tr Triple 7
M Mandy
S Schist Lake
Tr
Mine shaft
N North Main
S South Main
Tr Triple 7
Fault
Syncline / anticline
Younging direction
Intrusive rocks
Phantom, Kaminis, Annabel, Cliff Lake plutons
Boundary intrusions
Myo felsic intrusion
Missi Group
Fluvial sedimentary rocks
Flin Flon arc assemblage
Louis formation
Hidden formation
Douglas formation
Hilary formation
Key member
Undivided
Flin Flon formation
Millrock member
Creighton member
Blue Lagoon member
Club member
Unassigned volcanic rocks
Hook Lake Block
Unassigned volcanic rocks

Figure GS-1-2: *Simplified geology of the Flin Flon area, showing major structures; boxes indicate the area covered by recent 1:5000 bedrock mapping. Abbreviations: BLF, Burley Lake Fault; BRA, Beaver Road anticline; CCF, Creighton Creek Fault; CLF, Club Lake Fault; FFLF, Flin Flon Lake Fault; GLF, Green Lake Fault; HLS, Hidden Lake syncline; MF, Mandy Road Fault; RF, Rio Fault; RLF, Ross Lake Fault; RWF, Railway Fault.*

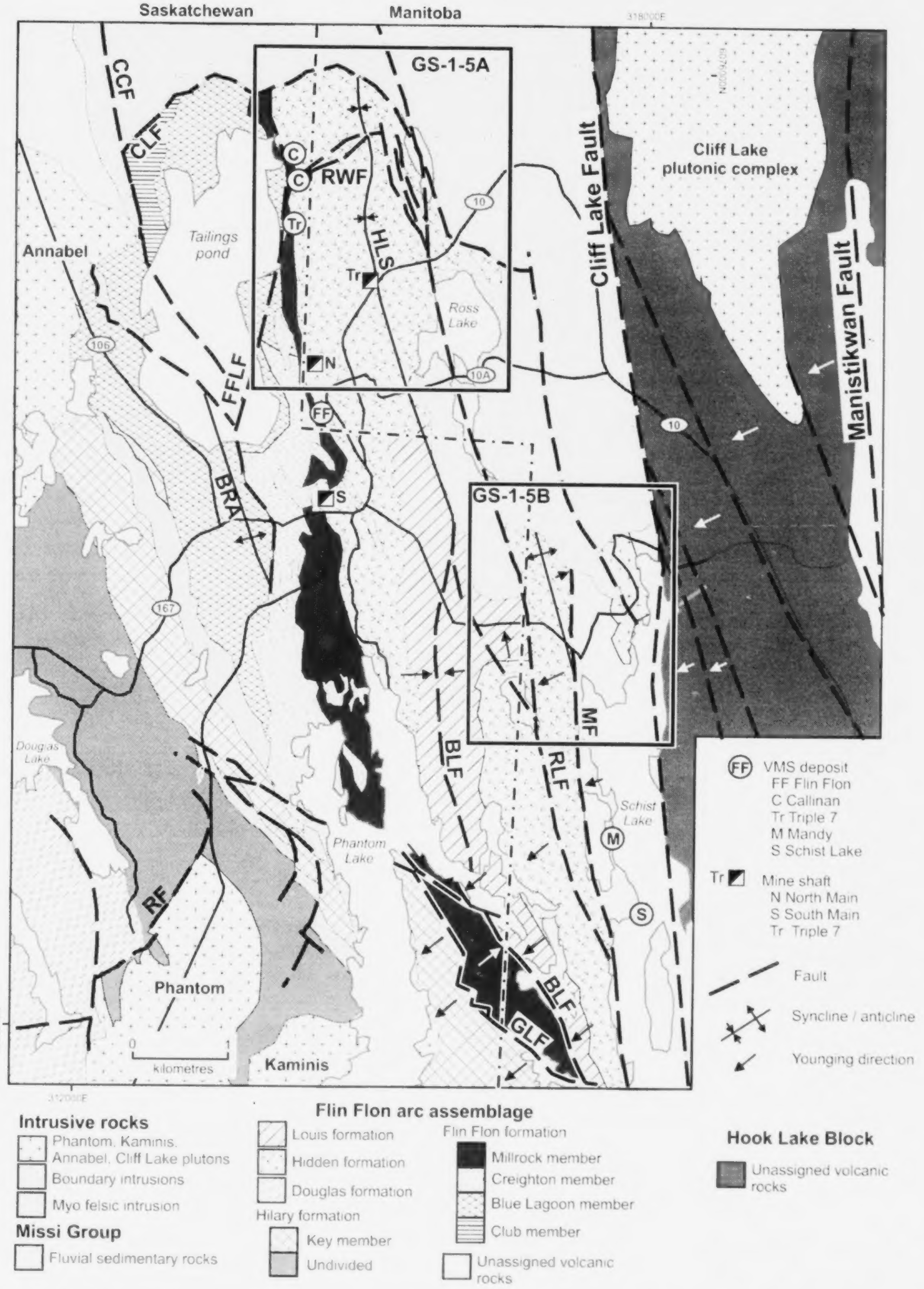
Saskatchewan
Manitoba
318000E
6070000N
GS-1-5A
GS-1-5B
CCF
CLF
C
C
RWF
Tr
HLS
Tr
N
FF
S
BRA
FFLF
Annabel
Tailings pond
Ross Lake
10
10A
106
167
Cliff Lake Fault
Cliff Lake plutonic complex
Manistikwan Fault
MF
RLF
BLF
BLF
GLF
RF
Douglas Lake
Phantom Lake
Schist Lake
M
S
Phantom
Kaminis
0
1
kilometres
312000E
FF VMS deposit
FF Flin Flon
C Callinan
Tr Triple 7
M Mandy
S Schist Lake
Tr Mine shaft
N North Main
S South Main
Tr Triple 7
Fault
Syncline / anticline
Younging direction
Intrusive rocks
Phantom, Kaminis, Annabel, Cliff Lake plutons
Boundary intrusions
Myo felsic intrusion
Missi Group
Fluvial sedimentary rocks
Flin Flon arc assemblage
Louis formation
Hidden formation
Douglas formation
Hilary formation
Key member
Undivided
Flin Flon formation
Millrock member
Creighton member
Blue Lagoon member
Club member
Unassigned volcanic rocks
Hook Lake Block
Unassigned volcanic rocks

Figure GS-1-2: *Simplified geology of the Flin Flon area, showing major structures; boxes indicate the area covered by recent 1:5000 bedrock mapping. Abbreviations: BLF, Burley Lake Fault; BRA, Beaver Road anticline; CCF, Creighton Creek Fault; CLF, Club Lake Fault; FFLF, Flin Flon Lake Fault; GLF, Green Lake Fault; HLS, Hidden Lake syncline; MF, Mandy Road Fault; RF, Rio Fault; RLF, Ross Lake Fault; RWF, Railway Fault.*

commonly 40–80% lichen-free outcrop. Regional metamorphism is lower-greenschist facies (epidote-chlorite; Bailes and Syme, 1989), with good preservation of primary textures. The extent of recent Manitoba Geological Survey (MGS) 1:5000 scale bedrock mapping in the Flin Flon area, which is discussed in this report, is shown in Figure GS-1-2.

Geological mapping and stratigraphic analysis of volcanic rocks of the Flin Flon mines area (Devine, 2003; Tardif, 2003; DeWolfe and Gibson, 2005, 2006; Gibson, unpublished data, 2000–2006) have established an informal stratigraphic subdivision of rocks occurring in the footwall, along strike and in the hangingwall of the Flin Flon, Callinan and Triple 7 massive sulphide deposits (Devine, 2003; DeWolfe and Gibson, 2005, 2006). Figure GS-1-3 summarizes this informal stratigraphy for the mine area and for equivalent rocks to the south in the Schist Lake–Mandy mines area (Simard, 2006a).

Mapping this past summer focused in three areas: 1) the Hidden Lake area, 2) the Mandy Road–Channing area, and 3) the Hook Lake block. The first two areas are discussed in this report and the third area in a separate report (Kremer and Simard, GS-2, this volume).

Hidden Lake area

Stratigraphy

The 1:5000 scale mapping in the Hidden Lake area in 2007 was focused south of the CN Rail line, in an area not previously covered by 1:2000 mapping by Y.M. DeWolfe (Figure GS-1-2; DeWolfe, 2007a–e). As previously described by DeWolfe and Gibson (2005, 2006), rocks in this area are mainly basaltic flows and intrusions with minor interflow tuff and volcaniclastic rocks. They belong to the Hidden formation, which is composed of the Reservoir member, a thick suite of aphyric, plagioclase-phyric and minor plagioclase-pyroxene–phyric mafic flows and sills with minor intercalated mafic tuff; the Stockwell member, a more localized strongly plagioclase-phyric series of basaltic flows with minor associated mafic volcaniclastic rocks; and the 1920 unit, a very localized andesitic cryptoflow of icelanditic composition (DeWolfe and Gibson, 2005, 2006). The latter two members occur in the thrust panels north of the CN Rail line.

The observed stratigraphy on the west limb and in the nose of the Hidden Lake syncline south of the CN Rail line is a sequence of aphyric, plagioclase-phyric

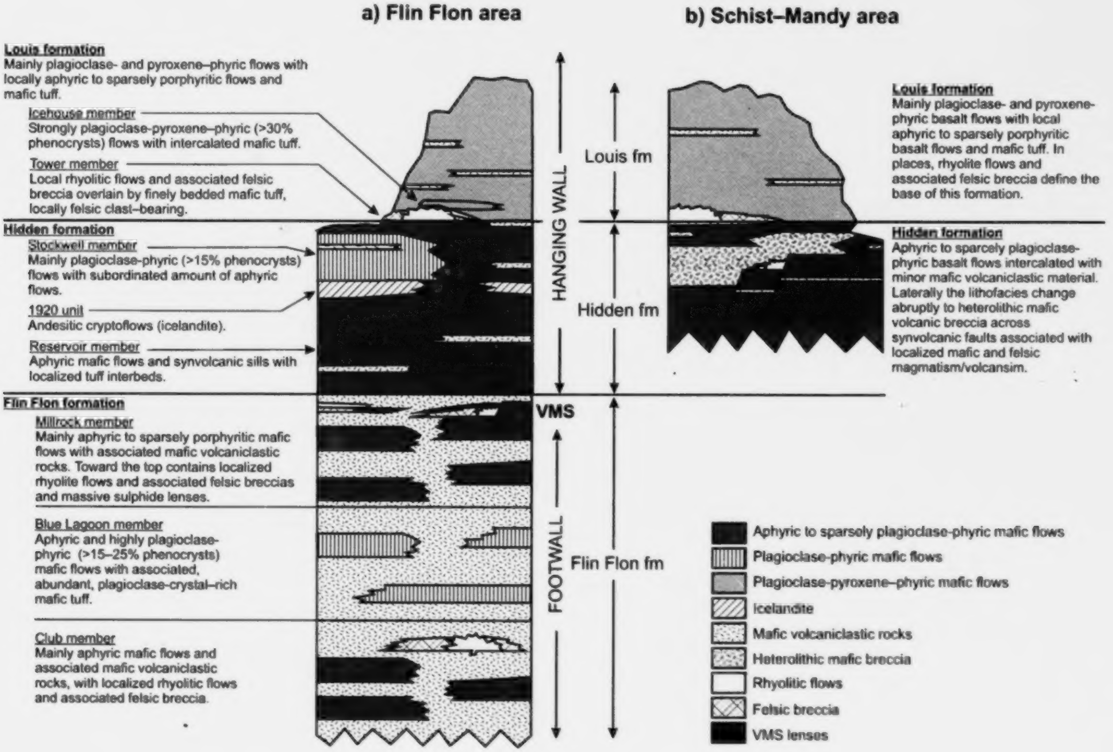
a) Flin Flon area
b) Schist–Mandy area
Louis formation
Mainly plagioclase- and pyroxene–phyric flows with locally aphyric to sparsely porphyritic flows and mafic tuff.
Icehouse member
Strongly plagioclase-pyroxene–phyric (>30% phenocrysts) flows with intercalated mafic tuff.
Tower member
Local rhyolitic flows and associated felsic breccia overlain by finely bedded mafic tuff, locally felsic clast–bearing.
Hidden formation
Stockwell member
Mainly plagioclase-phyric (>15% phenocrysts) flows with subordinated amount of aphyric flows.
1920 unit
Andesitic cryptoflows (icelandite).
Reservoir member
Aphyric mafic flows and synvolcanic sills with localized tuff interbeds.
Flin Flon formation
Millrock member
Mainly aphyric to sparsely porphyritic mafic flows with associated mafic volcaniclastic rocks. Toward the top contains localized rhyolite flows and associated felsic breccias and massive sulphide lenses.
Blue Lagoon member
Aphyric and highly plagioclase-phyric (>15–25% phenocrysts) mafic flows with associated, abundant, plagioclase-crystal–rich mafic tuff.
Club member
Mainly aphyric mafic flows and associated mafic volcaniclastic rocks, with localized rhyolitic flows and associated felsic breccia.
HANGING WALL
VMS
FOOTWALL
Louis fm
Hidden fm
Flin Flon fm
Louis formation
Mainly plagioclase- and pyroxene-phyric basalt flows with local aphyric to sparsely porphyritic basalt flows and mafic tuff. In places, rhyolite flows and associated felsic breccia define the base of this formation.
Hidden formation
Aphyric to sparcely plagioclase-phyric basalt flows intercalated with minor mafic volcaniclastic material. Laterally the lithofacies change abruptly to heterolithic mafic volcanic breccia across synvolcanic faults associated with localized mafic and felsic magmatism/volcansim.
Aphyric to sparsely plagioclase-phyric mafic flows
Plagioclase-phyric mafic flows
Plagioclase-pyroxene–phyric mafic flows
Icelandite
Mafic volcaniclastic rocks
Heterolithic mafic breccia
Rhyolitic flows
Felsic breccia
VMS lenses

***Figure GS-1-3:** Schematic stratigraphic section of the Flin Flon area: **a)** Flin Flon area schematic stratigraphy* (modified from *Devine, 2003; DeWolfe and Gibson, 2006); **b)** Schist Lake–Mandy mines area schematic stratigraphy (Simard, 2006a).*

and pyroxene-plagioclase–phyric pillowed and massive basaltic flows greater than 800 m thick (Simard et al., 2007). Conversely, the stratigraphy of the east limb of the Hidden Lake syncline in that same area is less than 300 m thick and composed almost entirely of plagioclase-phyric pillowed flows. All these rocks are part of the Reservoir member of the Hidden formation (DeWolfe and Gibson, 2006).

The aphyric flows in the area usually weather black and are dark green on fresh surfaces. The flows are generally aphyric to sparsely plagioclase phyric, with less than 2% plagioclase phenocrysts (<2 mm), and are generally 2–75 m thick, averaging 5–15 m (Figure GS-1-4a). The thicker massive flows have a medium- to coarse-grained base with ~2–5% amygdules (2–4 mm in diameter) appearing toward the middle; some show columnar jointing toward the base (Figure GS-1-4b). The amygdules slowly increase in size toward the top of the flows, where they can form gas cavities up to 5 cm in diameter. Massive flows are usually overlain by large (60–200 cm in diameter), closely packed, highly amygdaloidal (15–20%, 2–5 mm in diameter, quartz-filled) pillows showing thick (up to 2 cm), negatively weathered chilled margins.

The plagioclase-phyric flows usually weather buff brown and are dark green on fresh surfaces. The flows generally show 5–20% plagioclase phenocrysts (2–3 mm in diameter) and greatly vary in thickness. Plagioclase-phyric flows are usually pillowed (showing pillows 50–120 cm in diameter), amygdaloidal (20–25%, 2–3 mm in diameter, quartz-filled) and closely packed (Figure GS-1-4b). The pillows usually display a thin (1.5 cm thick) chilled margin with varying amounts (5–15%) of fine-grained interpillow tuffaceous material.

The plagioclase-pyroxene–phyric flows usually weather buff brown and are dark green on fresh surfaces. The flows generally have 10–15% plagioclase phenocrysts (2-3 mm in diameter) and approximately 10% pyroxene phenocrysts (1-4 mm in diameter), and are 1–20 m thick. Most flows are massive to pillowed and quartz amygdaloidal (5–15%, 23 mm in diameter), have small pillows 15–60 cm in diameter and are surrounded by up to 25% fine-grained interpillow material. The plagioclase-pyroxene–phyric flows, which comprise only 5% of the overall Hidden formation stratigraphy, are localized on the west limb of the Hidden Lake syncline.

A minor amount of mafic tuffaceous rocks can be found in the area. They form either a very thin veneer of very fine grained, well-bedded mafic tuff atop flows (Figure GS-1-4d) or localized, 1–5 m thick, laterally discontinuous, massive to well-bedded mafic lapilli tuff and tuff layers (Figure GS-1-4e).

Volcanic rocks in the Hidden Lake area are crosscut by numerous mafic dikes (aphyric, plagioclase phyric, plagioclase-pyroxene phyric and gabbroic), generally trending north to northwest. These mafic dikes are 0.3–3 m wide and can generally be followed over tens of metres in length. Fewer felsic dikes (aphyric and quartz-plagioclase phyric) are observed in the area. Their orientations seem random and they are more often found in proximity to shear zones.

Structure

Four major structural elements are present in the Hidden Lake area: 1) major curvilinear north-northeast– to east-trending Railway Fault(s), 2) the Hidden Lake syncline, 3) the Missi wedge structure and 4) the late north-northwest–trending strike-slip Ross Lake Fault (Figure GS-1-2, -5). The relative timing of these different structural events, with the exception of the late timing of the Ross Lake Fault, is currently unresolved to the satisfaction of geologists working in the area. The objective of the 2007 structural mapping program was to systematically document the distribution of the various foliations, lineations and shear zones in the area, in order to better understand the sequence of structural events in the area.

Upper and Lower Railway faults

The Upper and Lower Railway faults, which are locally exposed along the CN Rail line north of Hidden Lake (Figures GS-1-2, -5), are the most prominent of a set of bedding-parallel shear zones within the Hidden formation (Stockwell, 1960; Bailes and Syme, 1989; Thomas 1992; Gale et al., 1999). They form centimetre- to metre-wide dextrally reactivated ductile shear zones, with relict kinematic indicators (C/S fabrics) consistent with northward-thrusting movement along these structures (Fedorowitch et al., 1995; Gale, 1997). They also coincide with a prominent north-south break, from a high magnetic signature to the north, to low magnetic signature to the south, on the regional magnetic survey. Previous and recent mapping clearly document that they structurally juxtapose distinct portions of the Hidden formation stratigraphy on the west limb of the Hidden Lake syncline (Figure GS-1-2; DeWolfe and Gibson, 2006; DeWolfe, 2007a–c; Simard et al., 2007).

A thin package (~125 m thick) of aphyric and plagioclase-phyric basaltic flows trending approximately 020° and facing to the southeast occurs immediately south of the CN Rail line. This package extends east, close to the nose of the Hidden Lake syncline, but cannot be followed any farther (Figures GS-1-2, -5). The base of this package is not exposed anywhere to the north (CN tracks). Previous mapping has clearly shown that the rocks immediately to the north of the tracks are clearly different; the Upper Railway Fault is interpreted to separate the two packages (Figures GS-1-2, -5; Stockwell, 1960; Bailes and Syme, 1989; DeWolfe, 2007a, b).

Rocks immediately to the south of this thin package of flows consist of a very thick package (>800 m) of aphyric, plagioclase-phyric and minor plagioclase-pyroxene–phyric basaltic flows trending approximately 045° and facing to the southeast. The base of this southern

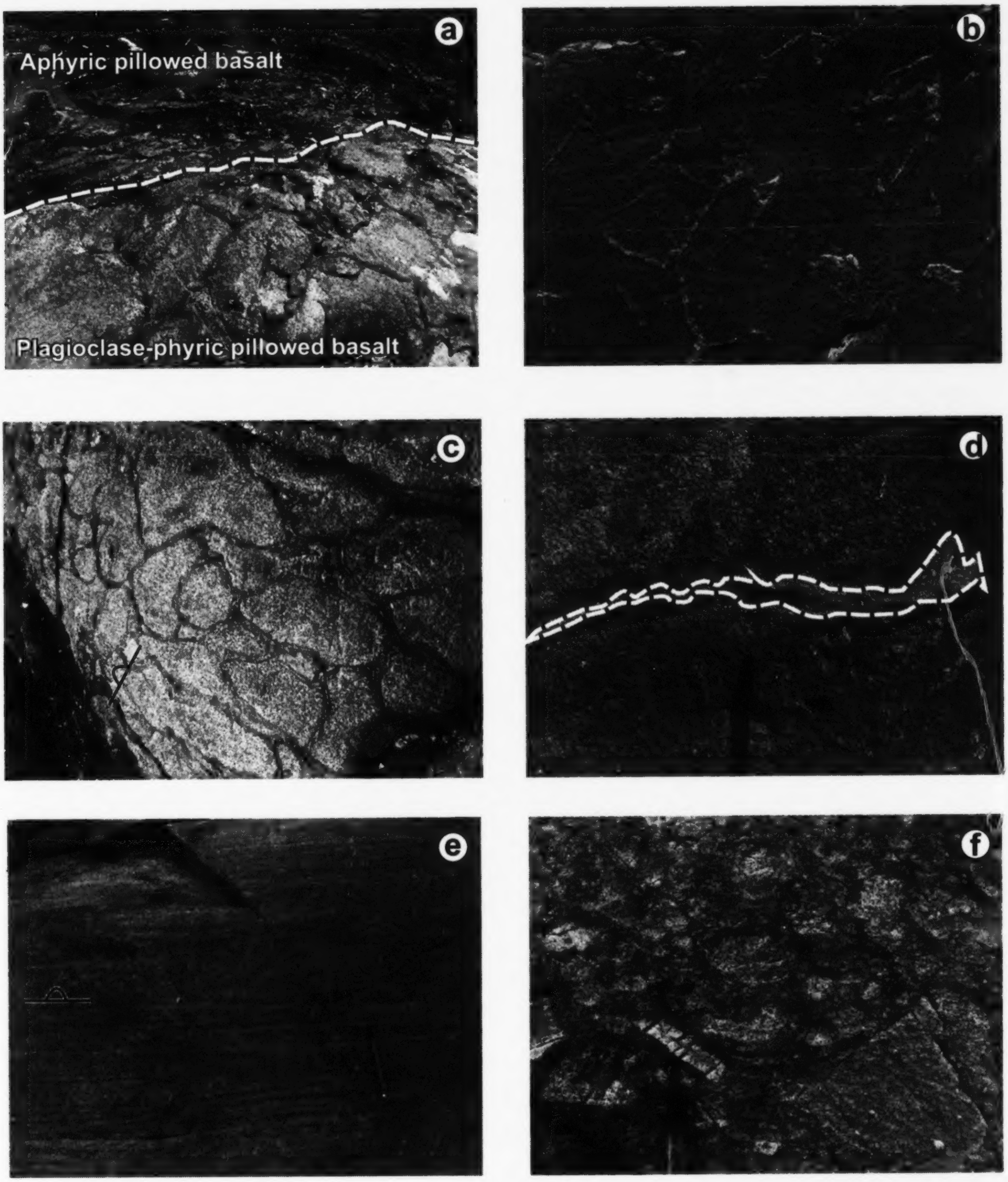

Figure GS-1-4: *Photographs of various volcanic rocks of the Hidden formation:* ***a)*** *contact between plagioclase-phyric pillowed flows (light coloured) and aphyric pillowed flows (dark coloured); photograph 10 m wide;* ***b)*** *columnar jointing at the base of a massive aphyric flow; tip of pen for scale;* ***c)*** *closely packed plagioclase-phyric pillowed flows; symbol indicates stratigraphic top;* ***d)*** *very fine grained, well-bedded mafic tuff atop massive basaltic flows; pen for scale;* ***e)*** *laterally discontinuous, massive to well-bedded mafic lapilli tuff; symbol indicates stratigraphic top; pen for scale;* ***f)*** *plagioclase-crystal–rich heterolithic mafic breccia showing mainly amygdaloidal aphyric basaltic clasts with a few angular tuffaceous clasts; pen for scale.*

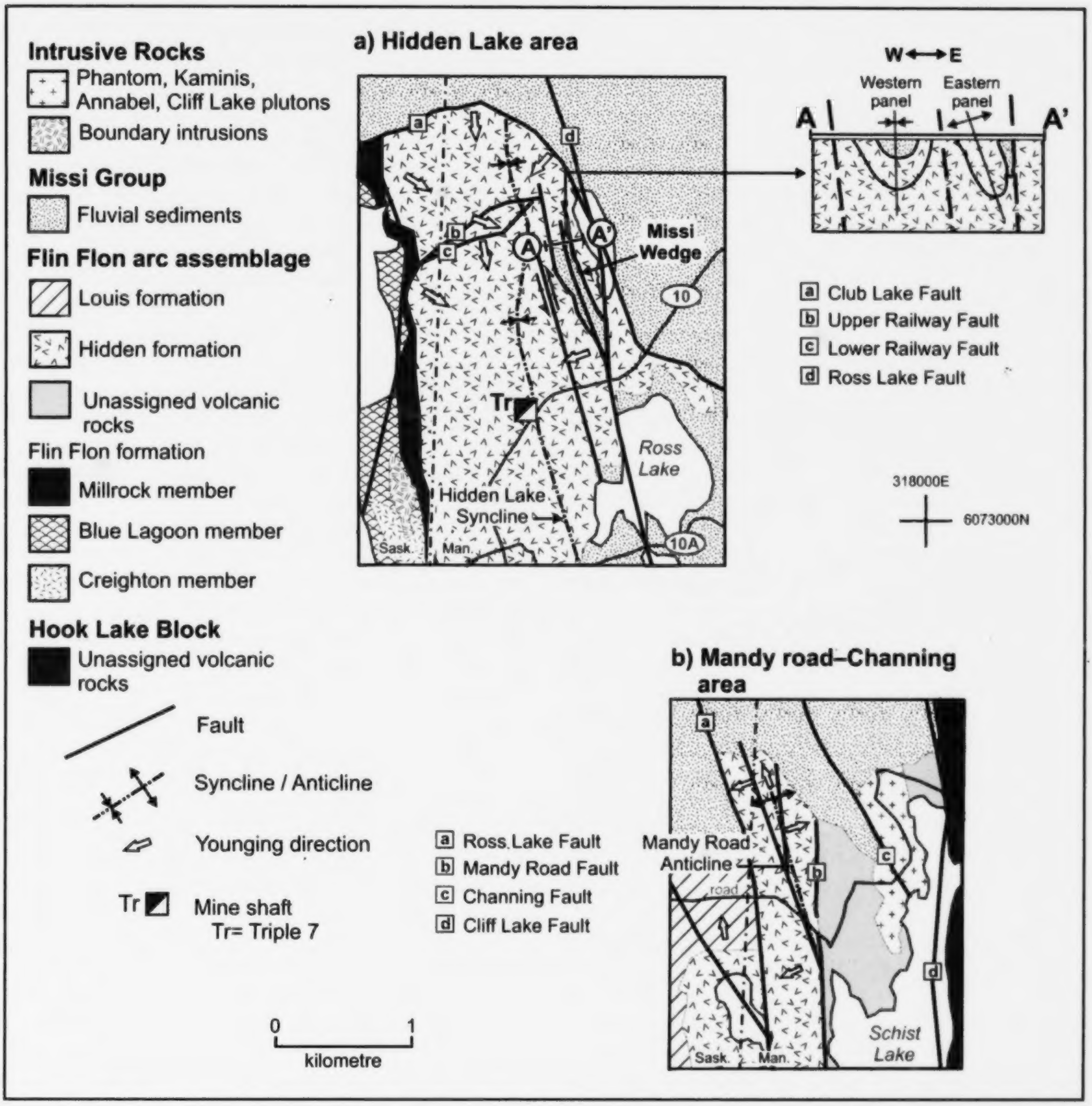
Intrusive Rocks
Phantom, Kaminis, Annabel, Cliff Lake plutons
Boundary intrusions
Missi Group
Fluvial sediments
Flin Flon arc assemblage
Louis formation
Hidden formation
Unassigned volcanic rocks
Flin Flon formation
Millrock member
Blue Lagoon member
Creighton member
Hook Lake Block
Unassigned volcanic rocks
Fault
Syncline / Anticline
Younging direction
Tr
Mine shaft
Tr= Triple 7
0
1
kilometre
a) Hidden Lake area
a
b
c
d
A
A'
Missi Wedge
10
Tr
Ross Lake
Hidden Lake Syncline
Sask.
Man.
10A
W↔E
Western panel
Eastern panel
A
A'
a Club Lake Fault
b Upper Railway Fault
c Lower Railway Fault
d Ross Lake Fault
318000E
6073000N
b) Mandy road–Channing area
a
b
c
d
Mandy Road Anticline
road
Sask.
Man.
Schist Lake
a Ross Lake Fault
b Mandy Road Fault
c Channing Fault
d Cliff Lake Fault

Figure GS-1-5: *Close-up of the **a)** Hidden Lake area, and **b)** Mandy Road–Channing area, outlining various structural elements.*

package is exposed in a cliff overhanging a small swampy valley between the two packages. The exposure displays a few dextral shear zones that are approximately 2 m wide, shallowly south-dipping and/or bedding-parallel and trending approximately 030°. These shear zones are interpreted to be the dextrally reactivated Lower Railway Fault (Figure GS-1-5a). The Lower Railway Fault is interpreted to be the base of this southern package of rock, which can be followed to the nose of the Hidden Lake syncline to the northeast, where it joins with the Upper Railway Fault (Figure GS-1-5a).

The eastern extensions of the Railway Faults have traditionally been portrayed as curving into the bounding faults of the Missi wedge structure (Stockwell, 1960; Bailes and Syme, 1989). Recent mapping, however, shows that the Missi wedge stratigraphy extends at least 100 m north of the CN Rail line (*see* details below; Simard et al., 2007; Hudson Bay Exploration and Development Co. Ltd., unpublished map). This suggests that the Railway Faults are truncated by the Missi wedge north-northwest–trending bounding shear zones (Figure GS-1-2), as was previously proposed by Gale (1997).

Hidden Lake syncline

The location of the Hidden Lake syncline south of the CN Rail line is facilitated by the high quality of exposure and good preservation of the volcanic flow internal structures. A north-northeast–trending east-southeast–facing succession of thick basaltic flows of the Reservoir member characterizes the west limb of the Hidden Lake syncline (Figure GS-1-5a). To the north, these flows gradually become east trending as the nose of the fold is approached. Rocks on the eastern limb of the syncline consist of a much thinner, slightly overturned north-northwest–trending, south-southwest–facing uniform succession of closely packed plagioclase-phyric basaltic flows, which are cut by the north-northwest–trending Missi wedge structures to the east (Figure GS-1-5a).

A relatively thin (~1–2 m thick) but laterally continuous, sinistral, south-southeast–trending shear zone occurs approximately 100 m east of the Hidden Lake syncline nose (Figure GS-1-5a). This shear zone, which can be followed south to Ross Lake and traced into an anastomosing system, is located exactly at the break in stratigraphy between the thick western limb and nose of the Hidden Lake syncline, and its thin eastern limb. It is also located exactly where a sharp break in the flow-facing direction occurs from the thick east-west flows in the nose of the fold to the west, and the south-southeast–trending thinner flows to the east (eastern limb of the syncline).

Volcanic rocks in the Hidden Lake area always display two distinct foliations: an early steeply dipping foliation trending approximately 345–350°, which is overprinted by a late shallowly dipping foliation that is trending 015°. North and east of the CN Rail line, the rocks of the east limb of the Hidden Lake syncline are much more deformed than those on the west limb. There they display a very strong, late, moderately dipping overprinting foliation that trends ~355°, parallel to the Ross Lake Fault to the east (Figure GS-1-5a).

A somewhat prominent stretching lineation, moderately plunging at 145–155°, is preserved as elongated amygdules and pillows (1:3–1:10 ratios) throughout the Hidden Lake area. This lineation is particularly prominent in the core of the Hidden Lake syncline southeast of Reservoir Lake.

Missi wedge structure

Recent mapping in the area of the Missi wedge structure has resulted in a better understanding of the internal stratigraphy of the wedge, and therefore its internal structure. The Missi wedge structure is composed of a series of narrow, fault-bounded wedges of both mafic volcanic (Hidden formation?) and fluvial sedimentary (Missi Group) rocks. They occur within the east limb of the Hidden syncline between a set of sinistrally reactivated, north-northwest–trending tear faults (Figures GS-1-2, -5b).

The Missi wedge structure consists of two north-northwest–trending fault-bounded panels, each presenting various amounts of fluvial sedimentary and mafic volcanic rocks (Figure GS-1-5a). The western panel is a gently south-dipping, upright, north-northwest–trending synclinal synform with mafic volcanic rocks to the north, and fluvial sedimentary rocks to the south, in the core of the syncline (Figure GS-1-5a). It is the most extensive panel of rocks in the wedge, and extends south to Highway 10. The eastern panel also consists of mafic volcanic and fluvial sedimentary rocks; however, it displays a north-northwest–trending, slightly west-verging anticlinal synform, with fluvial sedimentary rocks unconformably overlying mafic volcanic rocks only to the east (Figure GS-1-5a). These Missi Group rocks can be followed at least 100 m north of the CN Rail line, where they continue to directly overlie the mafic volcanic rocks to the east.

On the regional magnetic survey, the north-northwest Missi wedge structure coincides, especially north of the CN tracks, with a sharp north-northwest–trending break from a high magnetic signature to the west to a low magnetic signature to the east. Stratigraphy extended to the north of this feature and the abrupt north-northwest break in the magnetic survey both suggest that the Missi wedge structure extends well north of the tracks, and therefore crosscuts (and is younger than?) the Railway Faults (Figure GS-1-5a).

Ross Lake Fault

A surface expression of the Ross Lake Fault is not clearly exposed in the area. A potential expression of the fault is a zone of strong shearing just north of Highway 10 on the west side of the Missi wedge. At this locality, fluvial arkosic sedimentary rocks of the Missi Group, to the west, are in sheared contact with mafic volcanic rocks to the east. This zone of shearing extends south through mafic volcanic rocks, between Highway 10 and the water pipeline, and is finally lost in overburden and beneath Ross Lake to the south (Figure GS-1-2). Despite the lack of good exposure of the Ross Lake Fault in the area, its presence is manifest by a clear increase in strain in rocks immediately adjacent to the fault zone and the development of an overprinting ~350–360° foliation.

Mandy Road–Channing area

Stratigraphy

Rocks in the Mandy Road area are the northern extension of those in the Schist Lake–Mandy mines area (Figure GS-1-2; Simard, 2006a, b). The rocks between the Ross Lake and Mandy Road faults are composed mainly of aphyric basaltic flows with lesser amounts of plagioclase-crystal–rich heterolithic mafic breccia. The aphyric basaltic flow sequence is ~300 m thick and consists of 5–10 m thick massive basaltic flows with pillowed and/or amoeboid flow tops. Higher in the stratigraphy, the flows get thinner (2–4 m thick) and eventually only pillowed and amoeboid pillowed flows and amoeboid breccia are left. The plagioclase-crystal–rich heterolithic mafic breccia is massive to crudely bedded, and consists of variably amygdaloidal, subrounded to subangular aphyric basalt clasts (2–25 cm in diameter), with a few (<5%) angular clasts of fine-grained tuffaceous rocks (Figure GS-1-4f). The matrix is variable in composition, but usually has 5–15% plagioclase crystals 2–6 mm in diameter in fine-grained chloritic (mafic tuff?) material.

East of the Mandy Road Fault, rocks are mainly composed of heterolithic mafic breccia with minor aphyric basaltic flows. The heterolithic mafic breccia is massive and consists mainly of variably amygdaloidal, angular to subangular, aphyric basalt clasts (1–70 cm in diameter, averaging 5–7 cm) with a lesser amount of pyroxene-phyric basaltic clasts. The matrix is a fine-grained chloritic (mafic tuff?) material with some pyroxene (~5%) and plagioclase (<3%) crystals. The rocks in this area are intruded by fine- to medium-grained mafic intrusions, locally layered, as well as a late quartz-phyric medium-grained granodiorite.

Rocks in the Channing area are separated from those of the Mandy Road area by the Channing Fault, which offset the quartz-phyric granodiorite (Figures GS-1-2, -5). Not very well exposed, these rocks are composed mainly of massive aphyric basalt with a lesser amount of fine-grained, massive to bedded, mafic volcaniclastic rocks.

All the rocks in the area are unconformably overlain to the north by fluvial sedimentary rocks of the Missi Group (Figures GS-1-2, -4).

Structure

Volcanic rocks between the Ross Lake, Mandy Road, Channing and Cliff Lake faults are among the most deformed in the Flin Flon area (Figures GS-1-2, -5). Although identification of rock types and even volcanic facies is still possible, everything has been considerably flattened in a strong north-trending tectonic fabric, especially on approaching the Ross Lake Fault. This fabric commonly destroys top determination criteria and makes facing directions more challenging to identify than in the Hidden Lake area.

The Ross Lake–Mandy Road fault block is formed from a series of wedge-shaped panels of volcanic rocks, each with a slightly different trend and facing direction (Figure GS-1-5b). The westernmost panel faces west, the middle faces north and the easternmost faces east-northeast (Figure GS-1-5b). These facing direction changes all occur abruptly across narrow shear zones, often hidden in small gullies. The overall rotation of the facing directions is interpreted to be a manifestation of the Mandy Road anticline structure (*see also* Stockwell, 1960), modified by subsequent fault dismemberment (Figures GS-1-2, -5).

Volcanic rocks in the Mandy Road–Channing area always display two distinct foliations: an early, shallowly dipping foliation trending ~015°, overprinted by a late, steeply dipping foliation trending 345–350°. The latter foliation parallels the many narrow sinistral shear zones in the area.

Rocks between the Mandy Road and Channing faults are prominently foliated. They have the same two foliations as rocks in the Ross Lake–Mandy Road fault block but, in addition, contain a late, overprinting, moderately dipping foliation trending 330–335°, adjacent to the Channing Fault. This foliation, which is a product of ductile deformation in the volcanic rocks, is typically a brittle-cataclastic fabric in the quartz-phyric granodiorite, which is crosscut by the Channing Fault.

Rocks in the Channing area between the Channing and Cliff Lake faults display only the two foliations: the earlier, steeply dipping foliation trending 345–350° and the late, moderately dipping foliation trending 330–335°.

Geochemistry

Analytical techniques, alteration and sampling

Fifty representative rock samples were selected for geochemical analysis from a suite of over 150 specimens collected during the mapping of the Schist Lake–Mandy mines area. Major and trace-element compositions of all the analyzed samples are available in Data Repository Item DRI2007001[1].

All samples were analyzed at Activation Laboratories Ltd., Ancaster, Ontario, with major-element concentrations determined by x-ray fluorescence (XRF), trace elements and rare earth elements (REE) by inductively coupled plasma–mass spectrometry (ICP-MS; using fusion for sample preparation), and Sc by instrumental neutron activation analysis (INAA). Analytical error for the XRF method was <1% for major elements. For trace elements, precision is better than 6% and analytical error is better than 5% (Young, 2002). Eight samples were analyzed for Sm and Nd concentrations and Nd isotopic compositions at the Radiogenic Isotope Facility, University of Alberta, Edmonton, Alberta (Table GS-1-1).

Although primary minerals were replaced by lower-greenschist–facies metamorphic mineral assemblages, most major elements, high field-strength elements (HFSE), REE, Th and transition elements are considered to have been immobile during this lower-greenschist–facies metamorphism (e.g., Pearce and Cann, 1973; Winchester and Floyd, 1977; Wood, 1980; MacLean, 1990; Jenner, 1996). The consistency in compositional trends using both mobile and immobile elements in these volcanic rocks, and their similarities to those of modern igneous rocks, support the authors' interpretation that most major and trace elements were not significantly

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[1] MGS Data Repository Item DRI 2007001, containing the data or other information sources used to compile this report, is available online to download free of charge at http://www2.gov.mb.ca/itm-cat/freedownloads.htm, or on request from minesinfo@gov.mb.ca. or Mineral Resources Library, Manitoba Science, Technology, Energy and Mines, 360–1395 Ellice Avenue, Winnipeg, MB R3G 3P2, Canada.

Table GS-1-1: Neodymium and samarium isotopic analyses of volcanic rocks from of the Schist Lake–Mandy mines area.

Sample	Sm (ppm)	Nd (ppm)	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$	uncert.	TDM	~T(ma)	εNd(T)
105-06-19-4-3	3.21	11.96	0.1622	0.51236	0.00001	N/A	1900	2.9
105-06-31-1-1	3.74	14.41	0.1568	0.51230	0.00001	N/A	1900	3.1
105-06-92-2-1	1.20	3.84	0.1886	0.51263	0.00001	N/A	1900	1.8
105-06-96-2-2	1.48	6.01	0.1492	0.51210	0.00001	N/A	1900	1.1
105-06-111-2-1	4.27	16.71	0.1544	0.51228	0.00001	N/A	1900	3.4
105-06-139-1-1	2.64	10.33	0.1547	0.51223	0.00001	N/A	1900	2.4
105-06-157-1-1	1.85	6.22	0.1794	0.51254	0.00001	N/A	1900	2.3
105-06-164-1-1	1.46	5.50	0.1610	0.51237	0.00002	N/A	1900	3.4

affected by alteration or metamorphic processes. Thus, their distribution likely reflects primary magmatic trends.

Schist Lake–Mandy mines area

Rocks of the Schist Lake–Mandy mines area are divided into four different packages based on the observed stratigraphy: 1) the Hidden formation, 2) the Louis formation, 3) west of the Burley Lake Fault, and 4) east of the Mandy Road Fault (Simard, 2006a, b; Figure GS-1-2). Because many of them display major overlap in geochemical signatures, they are described together where applicable.

Mafic volcanic rocks

Most mafic flows in the Schist Lake–Mandy mines area are basalt to basaltic andesite with low Zr/TiO_2 (0.020–0.142) values (Figure GS-1-6a). The low Nb/Y (0.04–0.15) values suggest subalkaline affinity (Figure GS-1-6a).

The REE patterns of the mafic flows of the Hidden formation (Figure GS-1-7b) show a small light REE (LREE) enrichment ($(La/Yb)_N$ = 0.91–2.13) with a flat heavy REE (HREE) pattern. The REE patterns of the mafic flows of the Louis formation, as well as the basalt flows west of the Burley Fault and some of the basalt flows east of the Mandy Road Fault (Figure GS-1-7b, c), show a small to moderate LREE enrichment ($(La/Yb)_N$ = 1.30–4.53) with a flat HREE pattern. The flat HREE pattern suggests that the source areas(s) of these mafic magma(s) did not contain any garnet; therefore, they were probably produced from partial melting in the spinel peridotite field at <60 km depth (White et al., 1992).

The pronounced negative Nb and Ti anomalies on mantle-normalized trace-element diagrams (Figure GS-1-7b, c), low Ti/V ratios (Figure GS-1-6b) and distribution on the Th–(Zr/117)–Nb/16 (Figure GS-1-6c; Wood, 1980) and Zr/3–(Nb×2)–Y (Figure GS-1-6d; Meschede, 1986) diagrams all indicate mafic flows in the Schist Lake–Mandy mines area to be products of subduction-related processes in an oceanic arc environment. Their relatively low $(La/Yb)_N$ ratios and high FeO_{total}/MgO ratios clearly demonstrate a tholeiitic affinity.

Analyses of Sm-Nd isotopes from the mafic volcanic rocks of the Schist Lake–Mandy mines area display an overall range of $\varepsilon_{Nd(1900Ma)}$ values from +1.1 to +3.4 (Table GS-1-1). Hidden formation mafic flows show $\varepsilon_{Nd(1900Ma)}$ values from +1.8 to +3.4, whereas the mafic flows from west of the Burley Lake Fault and east of the Mandy Road Fault show $\varepsilon_{Nd(1903Ma)}$ values of +2.4 and +2.3, respectively. No mafic flows of the Louis formation were submitted from the Schist Lake–Mandy mines area, as several $\varepsilon_{Nd(1900Ma)}$ values have already been published for these rocks ($\varepsilon_{Nd(1900Ma)}$= +3.3 to +3.9; Stern et al., 1995a). The positive $\varepsilon_{Nd(1900Ma)}$ values of these rocks suggest a juvenile magma source with minimum involvement of continental crust in the magma genesis; however, the slightly less positive $\varepsilon_{Nd(1900Ma)}$ values for the Hidden formation rocks compared to the Louis formation rocks suggest potentially more contamination of the Hidden formation rocks.

Felsic volcanic rocks

Felsic volcanic rocks in the Schist Lake–Mandy mines area consist of isolated, small, massive to locally brecciated, plagioclase-quartz–phyric rhyolite flows/domes in both the Hidden and Louis formation rocks. The Hidden formation rhyolitic rocks are spatially associated with numerous, narrow, aphyric to quartz-plagioclase–phyric rhyolitic dikes, which cut Hidden formation rocks and are likely feeders to the flow/domes. The analyzed samples have high SiO_2 content (SiO_2 >72.7%) with low Nb/Y (0.07–0.08) and high Zr/TiO_2 (0.362–0.427) values (Figure GS-1-6a). The low Nb/Y values suggest subalkaline affinity (Figure GS-1-6a). The content of HFSE (Nb, Ta, Ga, Zr, Hf and Y), relative to other incompatible elements within these rocks, is moderate to low and characteristic of rocks generated in an oceanic arc environment (Figure GS-1-6c, -6d; Wood, 1980; Meschede, 1986).

The REE patterns of the felsic flows of the Hidden and Louis formations (Figure GS-1-7b) show slight LREE enrichment ($(La/Yb)_N$ = 1.76–2.23) with a relatively flat HREE pattern. These REE patterns are very similar to those of the mafic flows from the Hidden and

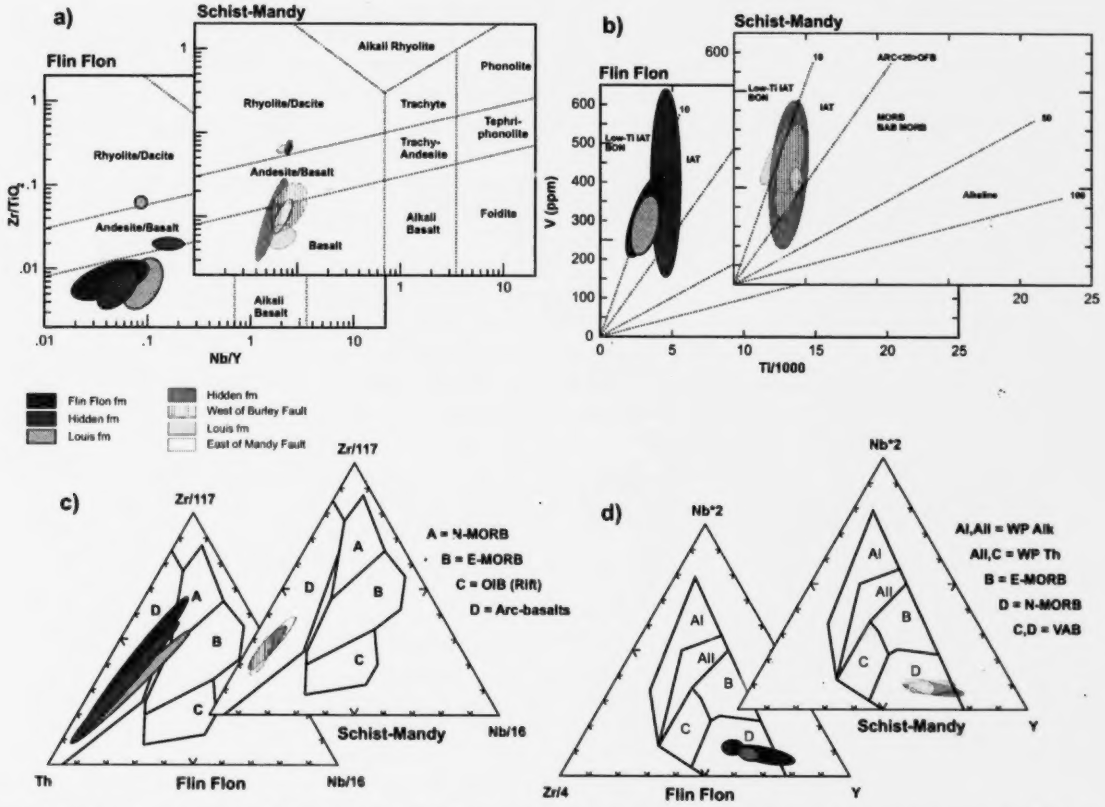

***Figure GS-1-6:** Geochemical characteristics of the volcanic rocks in the Schist Lake–Mandy mines area; **a)** Zr/TiO_2 vs. Nb/Y classification diagram (modified from Winchester and Floyd, 1976); **b)** V–(Ti/1000) diagram of Shervais (1982), with V/Ti <20 typical of arc and V/Ti >50 typical of alkali magmatism. Abbreviations: BAB, back-arc basalt; BON, boninite; IAT, island-arc tholeiite; MORB, mid-ocean-ridge basalt; OFB, ocean floor basalt; **c)** Th–(Zr/117)–(Mb/16) diagram from Wood (1980). Abbreviations: E-MORB, enriched-MORB; N-MORB, normal-MORB; OIB, ocean-island basalt; **d)** (Zr/4)/(Nb×2)/Y diagram of Meschede (1986). Abbreviations: alk, alkali; Th, tholeiite; VAB, volcanic arc basalt; WP, within-plate.*

Louis formations, suggesting that they are derived from the same source. Similar to the mafic flows in this area, felsic flows of the Schist Lake–Mandy mines area display pronounced negative Nb and Ti anomalies on the mantle-normalized trace-element diagrams (Figure GS-1-7b). This, plus their Ti/V ratio (Figure GS-1-6b) and their distribution on the Th–(Zr/117)–Nb/16 (Figure GS-1-6c; Wood, 1980) and Zr/3–(Nb×2)–Y (Figure GS-1-6d; Meschede, 1986) diagrams suggest subduction-related genesis in an oceanic arc environment.

Analyses of Sm-Nd isotopes of the felsic volcanic rocks from the Hidden formation show $\varepsilon_{Nd(1900Ma)}$ values of +3.1, whereas those from the Louis formation show $\varepsilon_{Nd(1903Ma)}$ values of +3.4 (Table GS-1-1). The positive $\varepsilon_{Nd(1900Ma)}$ values of these rocks, which are similar to mafic flows in the area, suggest a juvenile magma source with little involvement of continental crust in magma genesis.

Discussion and economic considerations

Flin Flon area stratigraphy

Extrapolating the Flin Flon–Callinan–Triple 7 mine stratigraphy, based on volcanic stratigraphy or geochemistry, beyond the immediate Flin Flon mine area has proven difficult. Proximal volcanic arc environments, such as those in which Flin Flon rocks were formed, display highly variable stratigraphy due to multiple volcanic centres, local subsidence structures and the sporadic nature of volcanic activity. These features make confident extrapolation of stratigraphy between two areas difficult, even when these areas are as close to one another as the Hidden Lake and Schist Lake–Mandy mines areas (5 km separation).

Rocks between the Ross Lake and Mandy Road faults, in the Schist Lake–Mandy mines area (Figure GS-1-2), are mainly thick aphyric basaltic flows with lesser amounts of plagioclase-crystal–rich heterolithic mafic breccia, and are most similar to those in the Hidden formation north of Flin Flon. Although a greater abundance of heterolithic mafic breccia and local enrichment in plagioclase crystals is somewhat compatible with the rocks belonging to the Blue Lagoon member of the Flin Flon formation (Figure GS-1-3), the presence of comformably overlying rocks of the Louis formation west

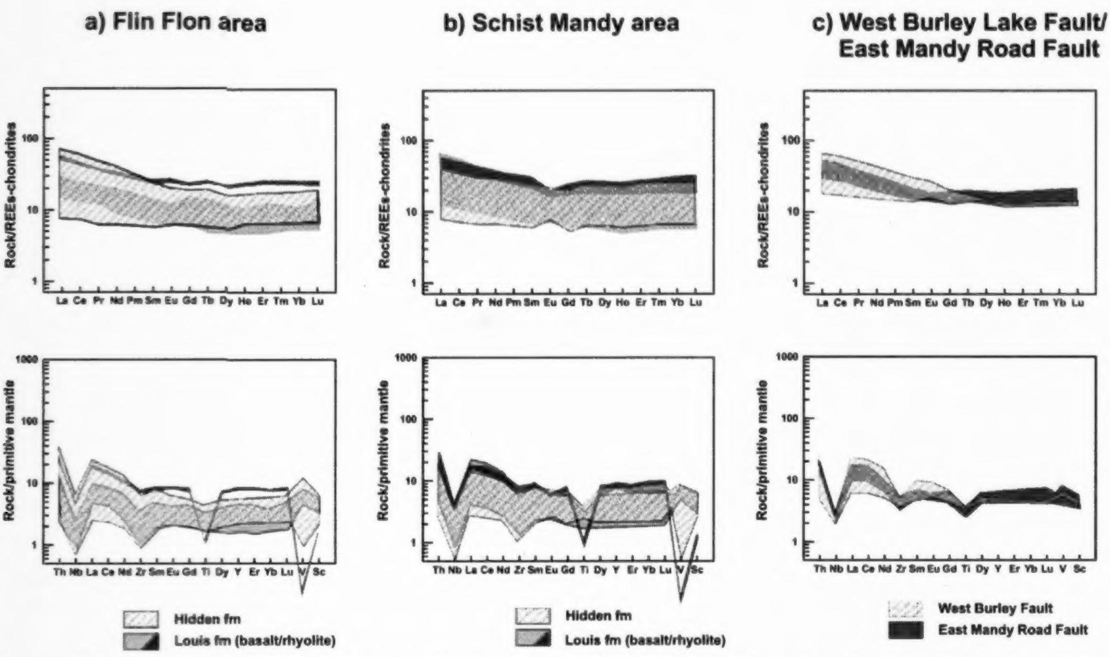

Figure GS-1-7: *Chondrite-normalized rare-earth-element patterns (normalization values* from *McDonough and Sun, 1995) and mantle-normalized incompatible trace-element patterns (normalization values* from *Sun and McDonough, 1989) for the volcanic rocks of* ***a)*** *the Hidden and Louis formations of the Flin Flon area,* ***b)*** *the Hidden and Louis formations of the Schist Lake–Mandy mines area, and* ***c)*** *west Burley Lake Fault and east Mandy Road Fault.*

of the Ross Lake Fault (Figure GS-1-2) is more consistent with the rocks belonging to the Hidden formation.

Rocks east of the Mandy Road Fault are heterolithic mafic breccia (not plagioclase-crystal rich) with minor aphyric basaltic flows, and are the hostrocks of the Schist Lake and Mandy VMS deposits to the south (Figure GS-1-2). If the Mandy Road Fault was not present, these rocks would be sitting just below the Hidden formation rocks to the west and be correlative with the hangingwall rocks of the Flin Flon–Callinan–Triple 7 VMS deposits. This has made a potential correlation with the main Flin Flon VMS stratigraphy enticing. In the Flin Flon main camp, however, the VMS-bearing Flin Flon formation does not have the abundant non-plagioclase–phyric heterolithic breccia that is seen east of the Mandy Road Fault. This suggests that the rocks east of the Mandy Road Fault, which include the rocks of the Schist Lake and Mandy mines, are not likely to be part of the Flin Flon–Callinan–Triple 7 mine stratigraphy.

Flin Flon area geochemistry

Although volcanic rock geochemistry is a powerful tool to characterize volcanic packages, it has limitations. This is particularly true when applied to very small areas where the differences between similar volcanic packages are small. Rocks of the Flin Flon–Callinan–Triple 7 mine stratigraphy display very similar whole-rock and isotopic geochemical signatures with only subtle variations, if any, between the footwall and hangingwall packages (Figures GS-1-6, -7; DeWolfe, pers. comm., 2007; Gibson, unpublished data, 2000–2007). The Flin Flon–Callinan–Triple 7 footwall and hangingwall volcanic rocks are both the result of tholeiitic arc volcanism (Syme et al., 1999) with relatively juvenile isotopic signatures (i.e., positive ε_{Nd} values of +2 to +5; Stern et al., 1995a, b). Thus, it is virtually impossible to differentiate rocks of the Flin Flon formation (footwall sequence) from those of the Hidden formation (hangingwall sequence) solely using geochemistry (Figures GS-1-6, -7). Within the hangingwall stratigraphy, small geochemical differences do exist between rocks of the Hidden and Louis formations, but there is also considerable overlap in their geochemical signatures that, once again, prevents differentiating these two formation based solely on geochemistry.

If the rocks of the Schist Lake–Mandy mines area are compared to those of the Flin Flon–Callinan–Triple 7 mine stratigraphy, they clearly show geochemical similarities (Figures GS-1-6, -7). The aphyric basaltic flows west of the Mandy Road Fault show the same geochemical characteristics as the typical Hidden formation aphyric basaltic flows of the Flin Flon mines area, with low Nb/Y and Zr/TiO_2 ratios as well as small LREE enrichment with a relatively flat HREE pattern on the REE and mantle-normalized trace-element diagrams (Figures GS-1-6, -7; DeWolfe, pers. comm., 2007). Farther west, the pyroxene-plagioclase–phyric basaltic flows on the peninsula in Phantom Lake show geochemical characteristics similar to the typical Louis formation pyroxene-plagioclase–phyric basaltic flows of the Flin Flon mines area, with low Nb/Y and Zr/TiO$_2$ ratios as well as moderate LREE enrichment and a flat HREE pattern on the REE and mantle-normalized trace-element diagrams (Figures GS-1-6, -7; DeWolfe, pers. comm., 2007). All the analyzed felsic volcanic rocks in the area, the Hidden and Louis formation flows/lobes and dikes alike, display a very similar geochemical signature when compared to the Flin Flon mine rhyolite.

The aphyric to pyroxene-plagioclase–phyric basaltic volcanic rocks west of the Burley Lake Fault share similarities with the Louis formation basalt, in particular their moderate LREE enrichment on the REE diagram. The scarcity of analyses for rocks east of the Mandy Road Fault, combined with their considerable variability, currently prevents any conclusive comparison to the Flin Flon–Callinan–Triple 7 mine package based on geochemistry.

Analyses of Sm-Nd isotopes from mafic and felsic volcanic rocks of the Schist Lake–Mandy mines area display an overall range of $\varepsilon_{Nd(1900Ma)}$ values (+1.8 to +3.4; Table GS-1-1) that is slightly lower than those published in the past for the volcanic rocks of the Flin Flon–Callinan–Triple 7 mine stratigraphy (+3.1 to +4.7; Stern et al., 1995b; DeWolfe, pers. comm., 2007). The slightly less positive $\varepsilon_{Nd(1900Ma)}$ values of these rocks suggest that their magma source may have undergone greater contamination by sedimentary rocks or older continental crust than previously documented for the rocks of the Flin Flon area.

Future work

Detailed mapping of both the structures and the volcanic facies, and thorough geochemical characterization of the volcanic rocks in the Flin Flon area have proven crucial to documenting and establishing the Flin Flon–Callinan–Triple 7 mine stratigraphy and more accurately assessing its extent in the area. It has enabled the ongoing production of a new 1:10 000 scale stratigraphic cross-border map for the Flin Flon area, and this will be crucial to the formulation of successful exploration models for this area.

More work is still required, and is in part currently underway (Lewis et al., in press; Lafrance, unpublished work, 2005–2007), to better understand the structural evolution of the immediate Flin Flon area. This is needed to better evaluate the timing and effects of the multiple deformation events (thrust faults, folds, strike-slip faults) on the distribution of the mine stratigraphy. Although individual structures, such as the Hidden Lake syncline, the Railway Faults, the Missi wedge structure and the Ross Lake Fault, are readily documented, their relative timing is still not adequately resolved.

More investigations (Cole et al., GS-3, this volume; Gibson, unpublished work, 2006–2007) are underway with the objective of resolving problems of correlation between the VMS-hosting units at the Schist Lake and Mandy mines (east of Mandy Road Fault) and those that host the Flin Flon, Callinan and Triple 7 orebodies.

Acknowledgments

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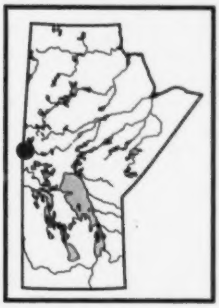
GS-2 Geology of the Hook Lake Block, Flin Flon area, Manitoba (part of NTS 63K12)

by P.D. Kremer and R-L. Simard



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Summary

The Hook Lake Block is one of several fault-bounded domains in the Flin Flon assemblage of the Paleoproterozoic Flin Flon Belt. It is bounded to the east and west by the Manistikwan Lake and Cliff Lake faults, respectively, and represents a comparatively unique volcanic and volcaniclastic stratigraphy with respect to the Flin Flon Block to the west. Based on field mapping of the northern segment of the Hook Lake Block in the summer of 2007, the area has been subdivided into two distinct sequences: 1) a western sequence consisting of aphyric to feldspar-phyric basaltic flows, associated volcaniclastic rocks with lesser felsic (quartz- and feldspar-phyric rhyolite) volcanic rocks, accompanied by a stratigraphically overlying sequence of reworked mafic and felsic proximal volcanic rocks interleaved with plagioclase- and pyroxene-phyric basaltic flows; and 2) an eastern sequence of massive to fragmental, quartz- and feldspar-phyric rhyolitic flows in a thick package of heterolithic mafic to mafic–felsic breccia. The western sequence is interpreted to be the product of proximal reworking of older mafic and felsic volcanic rocks accompanied by lesser mafic volcanism in a subsidence structure and/or basin. The eastern sequence is largely fragmental and also likely the product of infilling of a basinal domain by locally derived volcaniclastic detritus. The boundary between the two sequences is marked, in places, by the Cliff Lake pluton and elsewhere by the Hook Lake Fault. The latter is subparallel to, and has a similar kinematic history as, the block-bounding Manistikwan and Cliff Lake faults.

Sulphide mineralization (disseminated to semimassive/massive pyrite±pyrrhotite±chalcopyrite±sphalerite) was observed associated with massive to fragmental quartz- and feldspar-phyric rhyolite flows and domes throughout both sequences. This mineralization suggests that potential exists within the Hook Lake Block for volcanogenic massive sulphide (VMS) deposits. Small amounts of remobilized sulphide mineralization accompanied a minor sinistral reactivation event along the Cliff Lake Fault.

Introduction

The Flin Flon area of the Paleoproterozoic Flin Flon Belt is well known for its VMS deposits. Three active (Callinan, Triple 7 and Trout Lake) and three past-producing (Flin Flon, Mandy and Schist Lake) VMS mines occur in the immediate vicinity of the town of Flin Flon, which makes this area one of the most productive base-metal regions in Canada.

With the intent of stimulating private-sector mineral exploration in areas of high base-metal potential in established mining communities, the Government of Canada launched a new five-year Targeted Geoscience Initiative (TGI-3) in 2005. As part of this initiative, the Manitoba Geological Survey, in collaboration with the Saskatchewan Geological Survey, the Geological Survey of Canada and researchers from Laurentian University, is participating in production of a new 1:10 000 scale 'cross-border' geological map of the Flin Flon area.

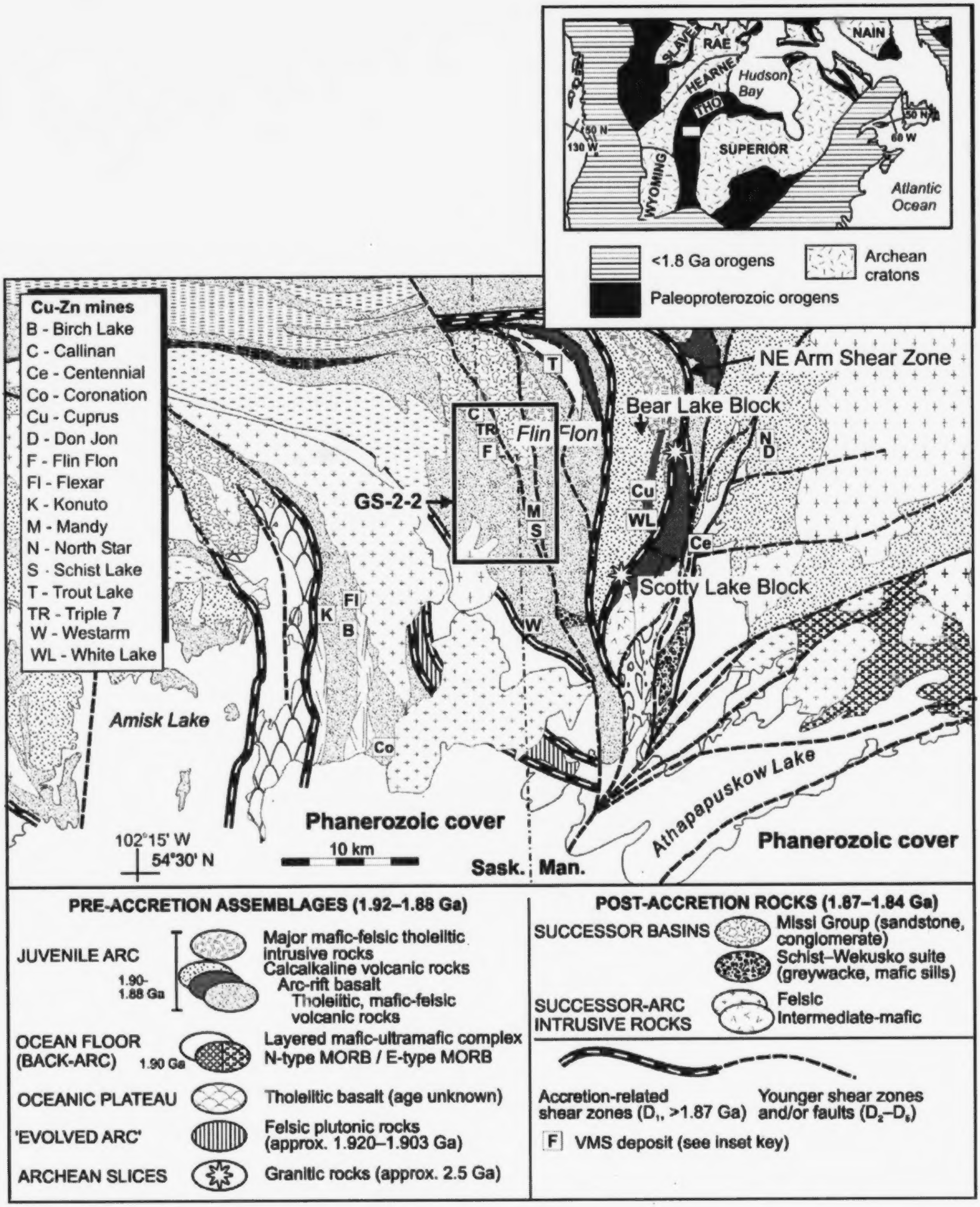
This report summarizes observations and data collected during the summer of 2007 on the rocks of the Hook Lake Block, located 1 km east of Flin Flon. The data were collected during the final three weeks of a twelve-week field program of 1:5000 scale bedrock geological mapping. The field and pending analytical studies in this area are intended to characterize and differentiate the various volcanic sequences, provide constraints on their distribution and assess whether these rocks are part of the same volcanic sequence that hosts the Flin Flon–Callinan–Triple 7 mines at Flin Flon.

Regional setting

The Paleoproterozoic Flin Flon Belt is part of the Reindeer Zone of the Trans-Hudson Orogen (Figure GS-2-1). The belt consists of a series of tectonostratigraphic assemblages (juvenile arc, juvenile ocean-floor back arc, ocean plateau, ocean-island basalt and evolved plutonic arc) that range in age from 1.92 to 1.87 Ga (Syme et al., 1999). All VMS deposits mined to date in the Flin Flon area are associated with the juvenile Flin Flon arc assemblage (Syme et al., 1999).

Volcanic rocks of the Flin Flon area are part of a 1.9 Ga juvenile arc assemblage, which consists mainly of tholeiitic subaqueous pillowed basalt and basaltic andesite, with lesser amounts of heterolithic mafic breccia and mafic and felsic volcaniclastic rocks, and minor dacite to rhyolite flows (Bailes and Syme, 1989). The VMS deposits at Flin Flon are spatially associated with felsic volcanic units in synvolcanic subsidence structures and calderas, within the main mafic volcanic complex (Bailes and Syme, 1989; Syme and Bailes, 1993; Figure GS-2-2).

Bailes and Syme (1989) subdivided the rocks of the Flin Flon area into structural blocks. Each block is fault bounded and displays unique units and stratigraphic sequences. Near Flin Flon, rocks west of the Cliff Lake



SLAVE
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NAIN
HEARNE
Hudson Bay
THO
50 N
130 W
SUPERIOR
WYOMING
50 N
60 W
Atlantic Ocean
<1.8 Ga orogens
Archean cratons
Paleoproterozoic orogens
Cu-Zn mines
B - Birch Lake
C - Callinan
Ce - Centennial
Co - Coronation
Cu - Cuprus
D - Don Jon
F - Flin Flon
Fl - Flexar
K - Konuto
M - Mandy
N - North Star
S - Schist Lake
T - Trout Lake
TR - Triple 7
W - Westarm
WL - White Lake
NE Arm Shear Zone
Bear Lake Block
Flin Flon
GS-2-2
Scotty Lake Block
Amisk Lake
Athapapuskow Lake
Phanerozoic cover
Phanerozoic cover
102°15' W
54°30' N
10 km
Sask.
Man.
PRE-ACCRETION ASSEMBLAGES (1.92–1.88 Ga)
JUVENILE ARC
1.90-1.88 Ga
Major mafic-felsic tholeiitic intrusive rocks
Calcalkaline volcanic rocks
Arc-rift basalt
Tholeiitic, mafic-felsic volcanic rocks
OCEAN FLOOR (BACK-ARC)
1.90 Ga
Layered mafic-ultramafic complex
N-type MORB / E-type MORB
OCEANIC PLATEAU
Tholeiitic basalt (age unknown)
'EVOLVED ARC'
Felsic plutonic rocks (approx. 1.920–1.903 Ga)
ARCHEAN SLICES
Granitic rocks (approx. 2.5 Ga)
POST-ACCRETION ROCKS (1.87–1.84 Ga)
SUCCESSOR BASINS
Missi Group (sandstone, conglomerate)
Schist–Wekusko suite (greywacke, mafic sills)
SUCCESSOR-ARC INTRUSIVE ROCKS
Felsic
Intermediate-mafic
Accretion-related shear zones (D1, >1.87 Ga)
Younger shear zones and/or faults (D2–D6)
F VMS deposit (see inset key)

Figure GS-2-1: *Geology of the Flin Flon Belt, showing locations of known volcanogenic massive sulphide (VMS) deposits (modified from Syme et al., 1999); box indicates the area covered by Figure GS-2-2; inset map shows the location of the Flin Flon Belt within the Trans-Hudson Orogen (THO).*

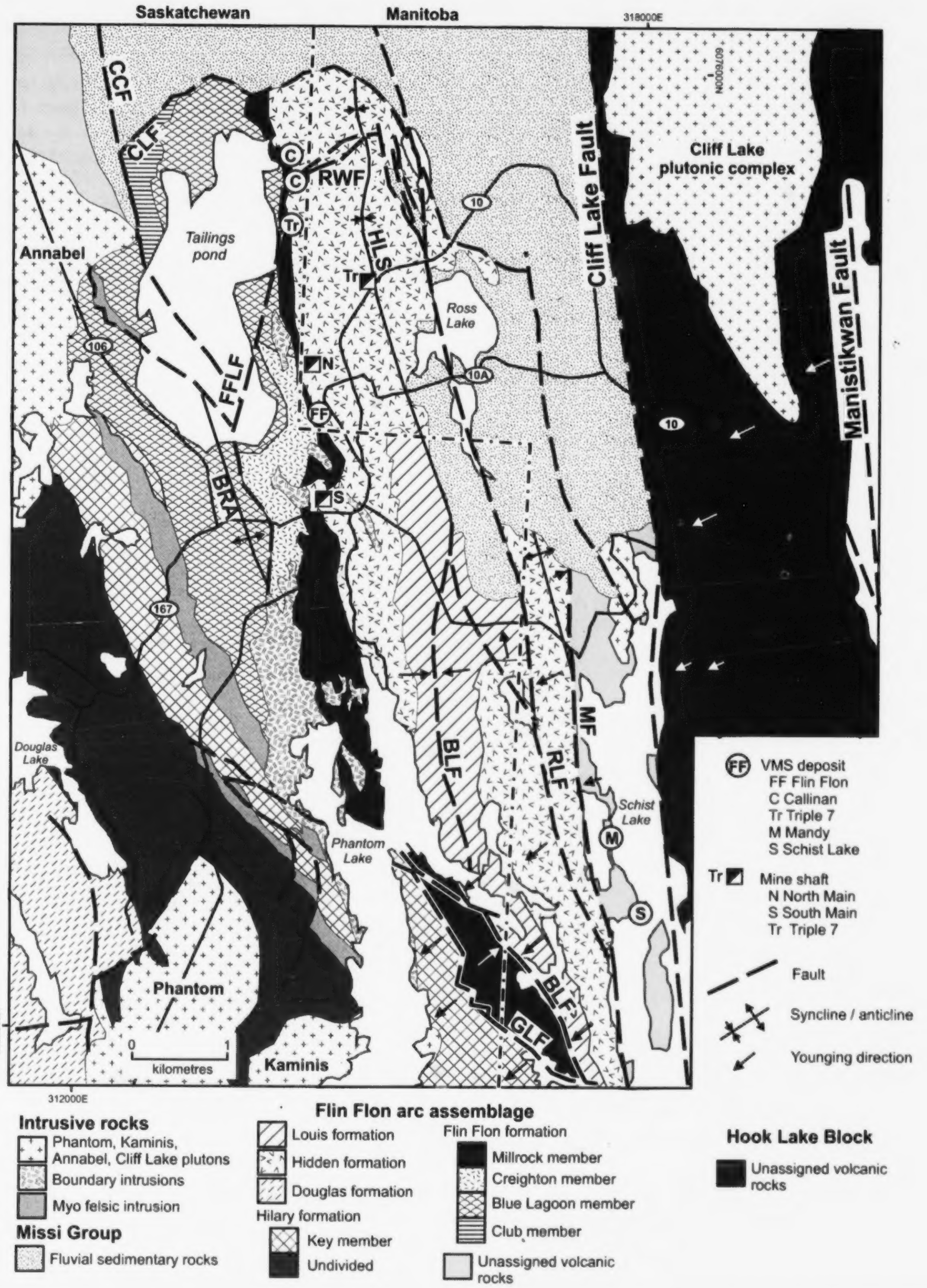
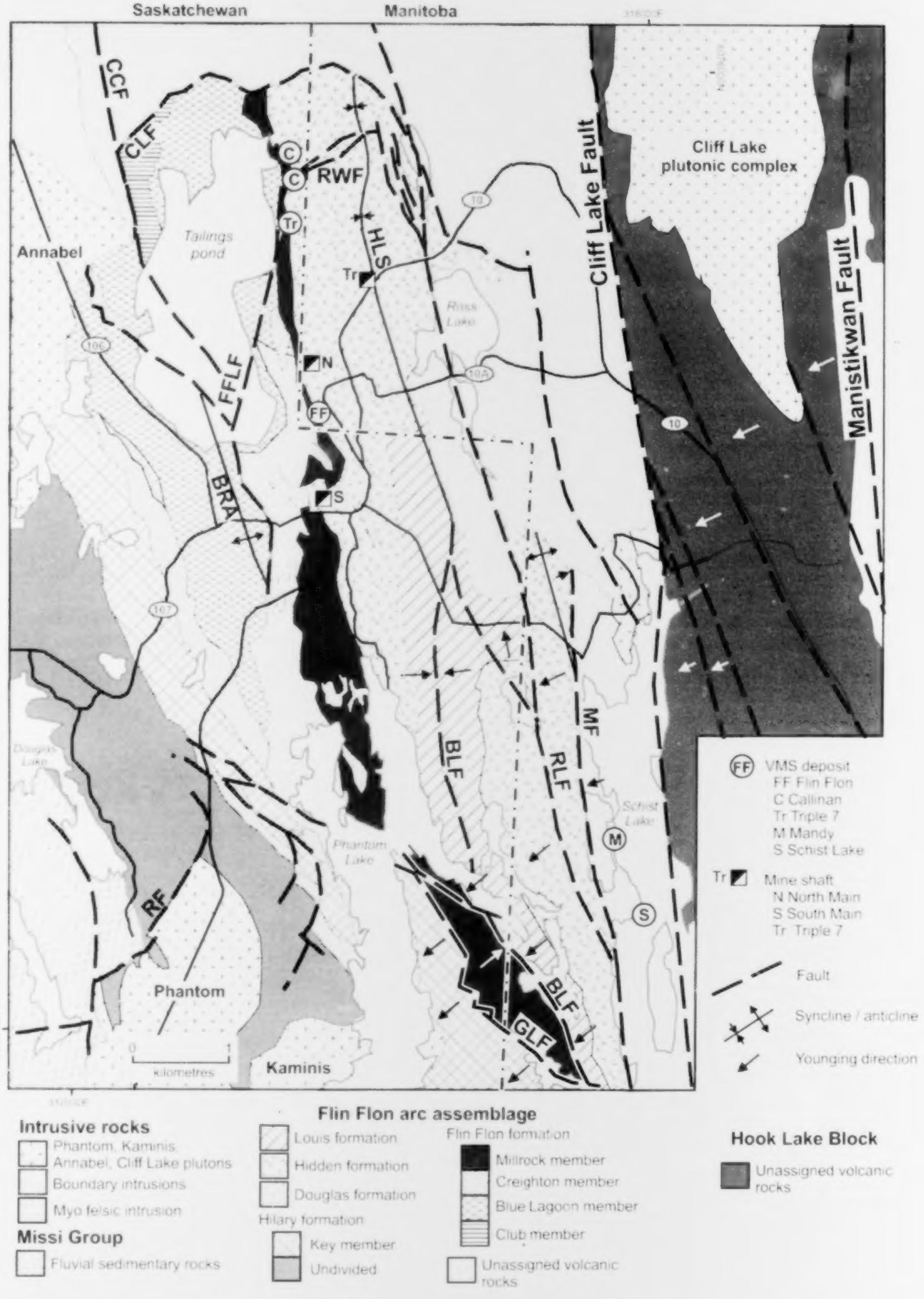

Saskatchewan
Manitoba
318000E
6076000N
312000E
6066000N
CCF
CLF
RWF
HLS
FFLF
BRA
BLF
RLF
MF
GLF
Cliff Lake Fault
Manistikwan Fault
Cliff Lake plutonic complex
Tailings pond
Annabel
Ross Lake
Douglas Lake
Phantom Lake
Schist Lake
Phantom
Kaminis
10
10A
106
167
C
Tr
N
FF
S
M
0
1
kilometres
FF VMS deposit
FF Flin Flon
C Callinan
Tr Triple 7
M Mandy
S Schist Lake
Tr Mine shaft
N North Main
S South Main
Tr Triple 7
Fault
Syncline / anticline
Younging direction
Intrusive rocks
Phantom, Kaminis, Annabel, Cliff Lake plutons
Boundary intrusions
Myo felsic intrusion
Missi Group
Fluvial sedimentary rocks
Flin Flon arc assemblage
Louis formation
Hidden formation
Douglas formation
Hilary formation
Key member
Undivided
Flin Flon formation
Millrock member
Creighton member
Blue Lagoon member
Club member
Unassigned volcanic rocks
Hook Lake Block
Unassigned volcanic rocks

Figure GS-2-2: *Simplified geology of the Flin Flon area, showing the major structures; boxes indicate the area covered by recent 1:5000 scale bedrock mapping. Abbreviations: BLF, Burley Lake Fault; BRA, Beaver Road anticline; FFLF, Flin Flon Lake Fault; GLF, Green Lake Fault; HLS, Hidden Lake syncline; MF, Mandy Road Fault; RF, Rio Fault; RLF, Ross Lake Fault; RWF, Railway Fault.*


Saskatchewan
Manitoba
CCF
CLF
RWF
HLS
FFLF
BRA
RF
BLF
RLF
MF
GLF
Cliff Lake Fault
Manistikwan Fault
Cliff Lake plutonic complex
Annabel
Tailings pond
Ross Lake
Douglas Lake
Phantom Lake
Schist Lake
Phantom
Kaminis
0 1 kilometres
C
Tr
N
FF
S
M
10
10A
106
167
FF VMS deposit
FF Flin Flon
C Callinan
Tr Triple 7
M Mandy
S Schist Lake
Tr Mine shaft
N North Main
S South Main
Tr Triple 7
Fault
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Flin Flon arc assemblage
Louis formation
Hidden formation
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Hilary formation
Key member
Undivided
Flin Flon formation
Millrock member
Creighton member
Blue Lagoon member
Club member
Unassigned volcanic rocks
Hook Lake Block
Unassigned volcanic rocks

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Fault belong to the Flin Flon Block, which includes the Flin Flon, Callinan and Triple 7 massive sulphide deposits. Rocks east of the Cliff Lake Fault, which are the subject of this report, belong to the Hook Lake Block (Figure GS-2-2).

Bedrock geology of the Hook Lake Block

The Hook Lake Block is bounded by the Manistikwan Lake Fault on the east, and the Cliff Lake Fault on the west (Bailes and Syme, 1989; Figure GS-2-2). Mapping in the Hook Lake Block during 2007 focused on the northern portion (Figure GS-2-2). The simplified geology of the area is shown in Figure GS-2-3.

Bedrock exposure in the Hook Lake Block is generally very good and consists of approximately 30–50% lichen-free outcrop that decreases in amount, size and quality east of the Cliff Lake plutonic complex (Figure GS-2-3). The exposed sequence faces west to southwest (Bailes and Syme, 1989) and, according mapping in 2007 and unpublished geochemical data (K. Gilmore, pers. comm., 2007), consists of two distinct volcanic sequences separated by the Hook Lake Fault and the Cliff Lake plutonic complex (Figure GS-2-3, -4). Variably textured mafic and felsic dikes and plugs intrude both sequences.

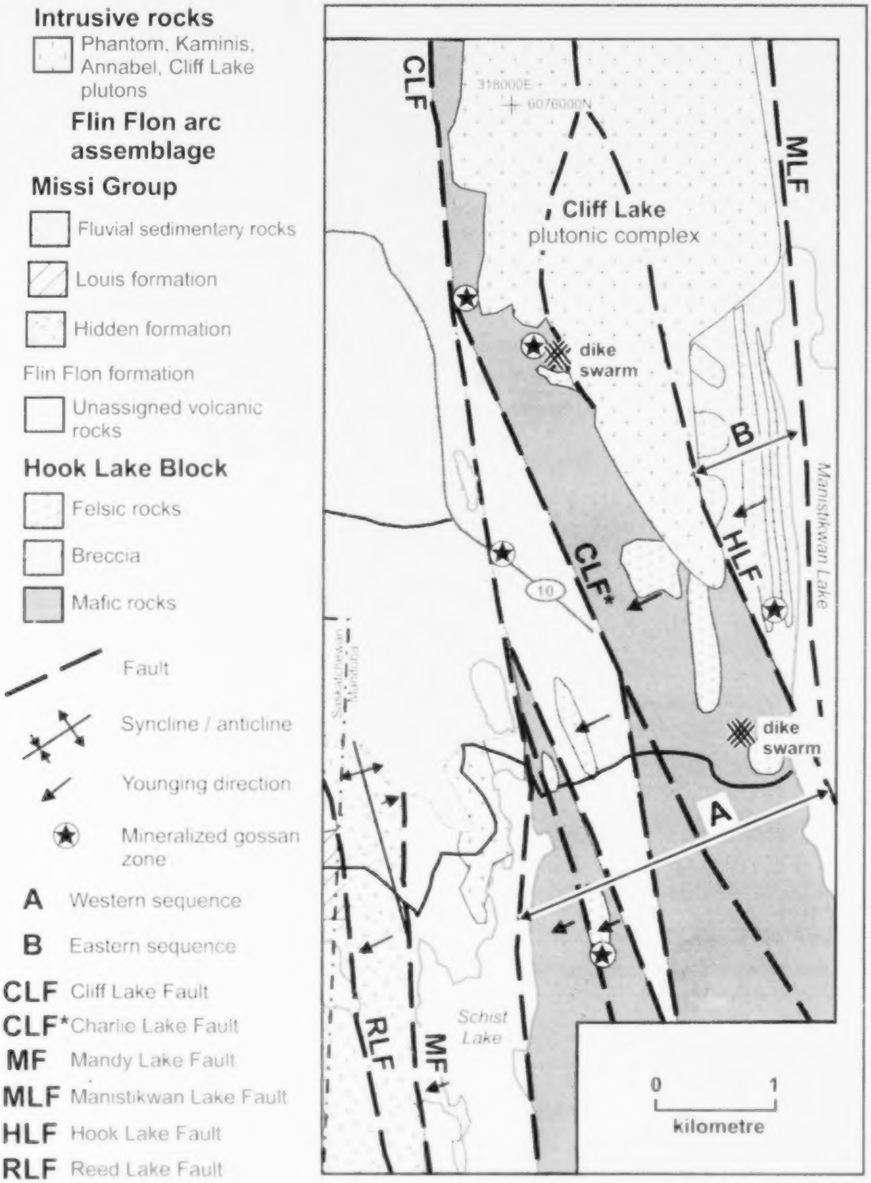
Intrusive rocks
Phantom, Kaminis, Annabel, Cliff Lake plutons
Flin Flon arc assemblage
Missi Group
Fluvial sedimentary rocks
Louis formation
Hidden formation
Flin Flon formation
Unassigned volcanic rocks
Hook Lake Block
Felsic rocks
Breccia
Mafic rocks
Fault
Syncline / anticline
Younging direction
Mineralized gossan zone
A Western sequence
B Eastern sequence
CLF Cliff Lake Fault
CLF* Charlie Lake Fault
MF Mandy Lake Fault
MLF Manistikwan Lake Fault
HLF Hook Lake Fault
RLF Reed Lake Fault
CLF
318000E
6076000N
MLF
Cliff Lake plutonic complex
dike swarm
B
Manistikwan Lake
HLF
CLF*
10
dike swarm
A
Saskatchewan
Manitoba
RLF
MF
Schist Lake
0
1
kilometre

Figure GS-2-3: Simplified bedrock geology of the Hook Lake Block, Flin Flon, Manitoba.

Fault belong to the Flin Flon Block, which includes the Flin Flon, Callinan and Triple 7 massive sulphide deposits. Rocks east of the Cliff Lake Fault, which are the subject of this report, belong to the Hook Lake Block (Figure GS-2-2).

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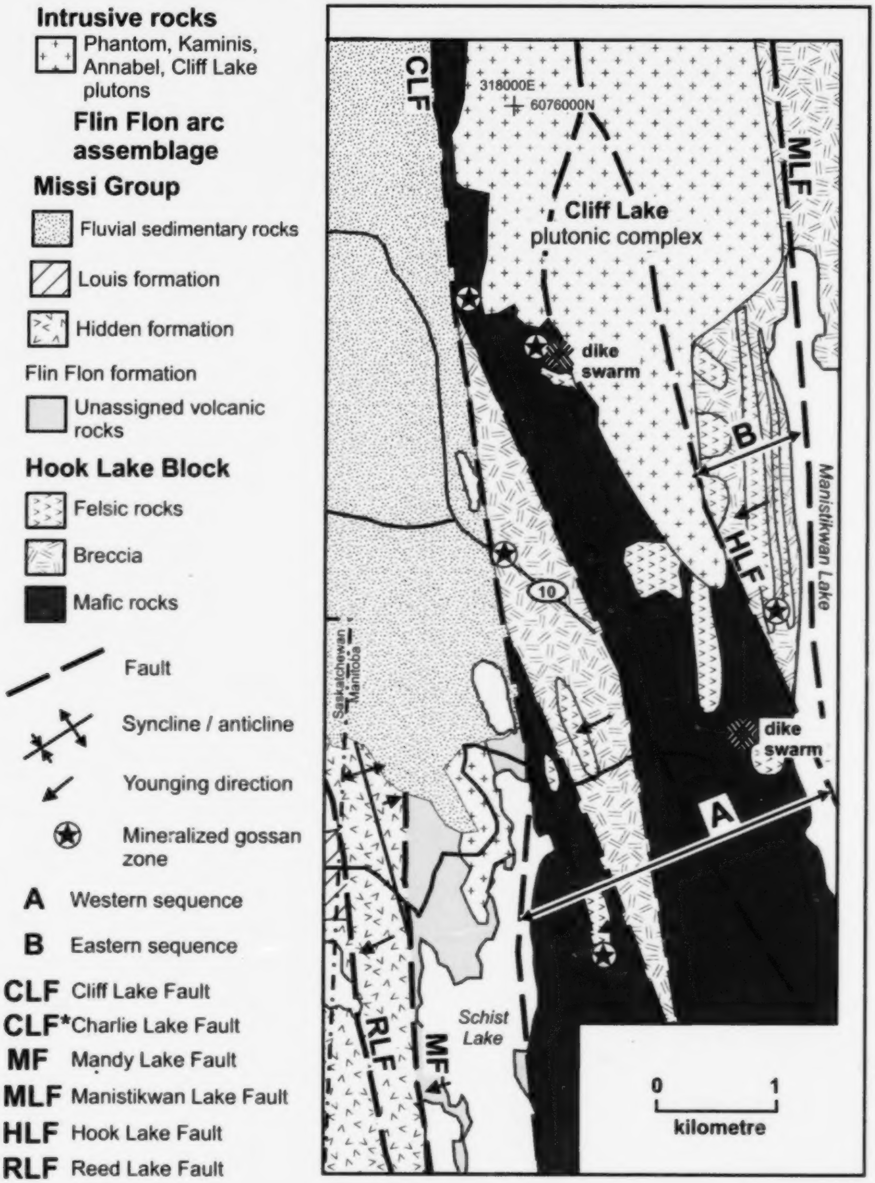
Intrusive rocks
Phantom, Kaminis, Annabel, Cliff Lake plutons
Flin Flon arc assemblage
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A Western sequence
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RLF Reed Lake Fault
CLF
318000E
6076000N
Cliff Lake plutonic complex
MLF
dike swarm
B
Manistikwan Lake
HLF
10
Saskatchewan
Manitoba
dike swarm
A
Schist Lake
RLF
MF
0
1
kilometre

Figure GS-2-3: Simplified bedrock geology of the Hook Lake Block, Flin Flon, Manitoba.

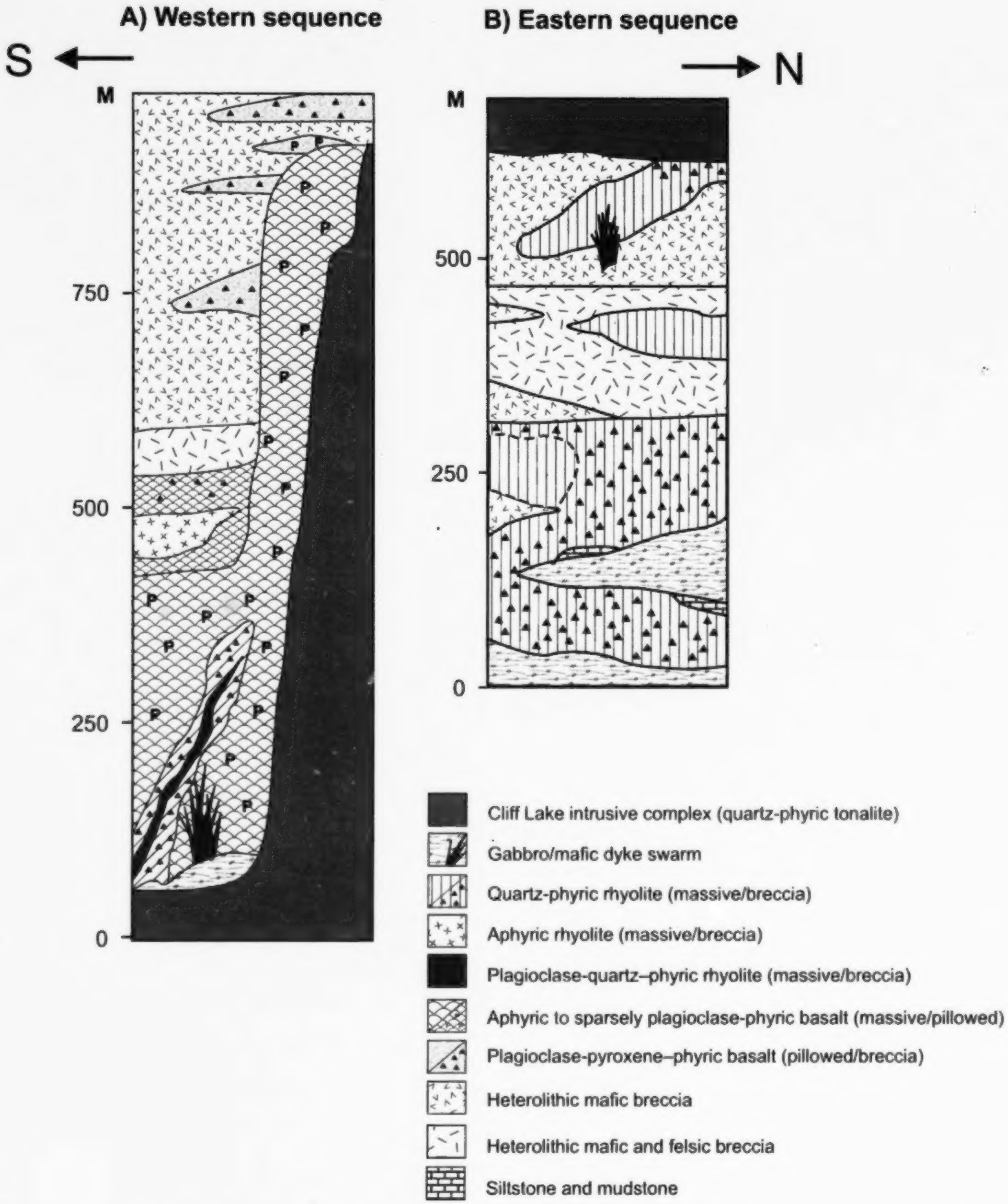
A) Western sequence
B) Eastern sequence
S
N
M
750
500
250
0
M
500
250
0
Cliff Lake intrusive complex (quartz-phyric tonalite)
Gabbro/mafic dyke swarm
Quartz-phyric rhyolite (massive/breccia)
Aphyric rhyolite (massive/breccia)
Plagioclase-quartz–phyric rhyolite (massive/breccia)
Aphyric to sparsely plagioclase-phyric basalt (massive/pillowed)
Plagioclase-pyroxene–phyric basalt (pillowed/breccia)
Heterolithic mafic breccia
Heterolithic mafic and felsic breccia
Siltstone and mudstone

***Figure GS-2-4:** Schematic stratigraphic section of the Hook Lake Block, Flin Flon: **a)** western sequence, **b)** eastern sequence.*

All rocks in the area are moderately to highly fractured and show varying amounts of alteration. Rocks up to 0.5 km west of the Cliff Lake intrusive complex are hornfelsed. Samples of all rock types were collected for thin section and whole rock geochemical analysis. Results are pending.

The western sequence, located between the Cliff Lake plutonic complex and the northwest-trending Hook Lake Fault, consists largely of aphyric to sparsely feldspar-phyric,basaltic flows and strongly feldspar-phyric basaltic flows and associated volcaniclastic rocks. It also includes lesser amounts of variably quartz-feldspar–phyric rhyolitic flows and domes, and overlying heterolithic mafic to mafic–felsic breccia interlayered with plagioclase- and pyroxene-phyric pillowed and amoeboid pillowed basaltic flows and breccia (Figure GS-2-4). This sequence is equivalent to the Grant Lake sub-block of the Hook Lake Block, as defined by Bailes and Syme (1989).

The eastern sequence, located east of the Cliff Lake plutonic complex and the northwest-trending Hook Lake Fault, consists of poorly exposed massive to fragmental quartz- and feldspar-phyric rhyolite flows in a thick package of heterolithic mafic to mafic–felsic breccia (Figure GS-2-4).

Western sequence

Volcanic rocks

Aphyric to sparsely feldspar-phyric basalt flows

A thick sequence of southwest-facing, aphyric to sparsely feldspar-phyric basaltic flows occurs at the base of the western sequence. They are best exposed between Highway 10 and the northwest arm of Schist Lake and, to the north, immediately west of the Cliff Lake plutonic complex. The basalt weathers brown to black and is dark grey to green on fresh surfaces. Individual flows include pillowed and/or massive, and amoeboid basalt capped by amoeboid flow-top breccia. In the north, thick 30–60 m successions of pillowed flows are intercalated with minor massive basaltic flows. In the south, massive basalt forms approximately 30% of observed flows. They are generally <10 m thick and characterized by lack of internal structure; oblate to irregular, elongate zones of epidosite alteration; and an increase in quartz-feldspar–filled amygdules (10%) and quartz-filled gas cavities (up to 5 cm) towards their top. Thick upper selvages and thermal contraction cracks were observed at the tops of a few massive flows. Pillowed basalt is abundant and forms the basal unit of individual flows where massive basalt is absent. Throughout this western sequence, pillow selvages are well developed and nonrecessive, and range between 0.5 and 1.5 cm in thickness. Pillow size decreases upsection, from 0.5–2.5 m at the base to 0.2–0.8 m at the top. Pillows are close packed and flows contain <15% epidotized hyaloclastic interpillow material. Syngenetic hydrothermal quartz-epidote alteration occurs throughout pillowed flows and is most pronounced in pillow cores (Figure GS-2-5a). Centimetre-scale concentric zoning from the selvage to the core of individual pillows is locally present (Figure GS-2-5b). Up to 30% quartz–, quartz-feldspar– or chlorite–filled amygdules (1–10 mm) are common throughout pillowed flows, with larger amygdules concentrated at the rims and smaller ones concentrated in the cores of individual pillows. Pillow forms are generally well preserved and locally indicate southwest younging. Amoeboid breccia contains 10–40 cm irregular clasts within highly epidotized matrix, and occurs at the top of most aphyric flows.

Complete aphyric flow assemblages are readily mapped where relatively clean and continuous exposure exists. Measured flow thickness is variable, and ranges from as little as 10 m up to 75 m. Although centimetre- to metre-scale parasitic folds exist throughout aphyric mafic flows, stratigraphic relationships and pillow morphology consistently indicate southwest tops and the sequence to be homoclinal.

Aphyric basalt grades westward into weakly feldspar-phyric varieties with <5%, fine-grained (1–2 mm), euhedral feldspar phenocrysts. No sharp contacts were observed between the two units, and the transition seems to be at a consistent distance from the Cliff Lake plutonic complex to the east. The latter may reflect destruction of the small feldspar phenocrysts in the contact metamorphic aureole of the intrusion rather than an 'appearance' at a specific distance from the pluton.

Feldspar-phyric basalt

A thin veneer of feldspar-phyric mafic breccia occurs within aphyric basaltic flows at the south margin of the map area, west of Highway 10. The unit is clast supported, with <10% fine-grained, strongly foliated chloritic matrix containing abundant plagioclase crystal fragments up to 3 mm in size. Clasts are composed exclusively of moderately to strongly feldspar-phyric basalt with 15–20%, 2–5 mm, euhedral to subhedral plagioclase phenocrysts. Approximately 10% quartz- and feldspar-filled amygdules (1–2 mm) are present in all clasts. Clasts are rounded to subangular and 5–25 cm in size, and locally show moderate degrees of stretching with weak subparallel alignment. One narrow body of pillowed feldspar-phyric basaltic flow was observed but could not be traced. Feldspar-phyric basaltic flows are not present in the stratigraphy in the northern part of the map area.

Quartz- and feldspar-phyric rhyolite

Rhyolite weathers buff white and is pale blue-grey on fresh surfaces. It contains 5–10%, 2–5 mm quartz±feldspar phenocrysts. Massive rhyolite, which is homogeneous throughout its extent, usually has associated lenses of weakly to well-developed autoclastic breccia occurring at the top or on the lateral margins of massive rhyolitic flows/domes. At one locality, west of the Cliff Lake pluton, a mafic dike swarm with associated felsic dikes and gossanous mineralized zone can be traced eastward in the stratigraphically underlying mafic volcanic rocks beneath a large quartz-feldspar–phyric rhyolitic flow and breccia. Numerous gossan zones and sulphide occurrences were observed in close association with rhyolitic flows and breccia units throughout the Hook Lake Block (Figure GS-2-3; *see* 'Discussion and economic considerations' section).

Foliation in the rhyolitic rocks is generally manifested as sets of spaced to closely spaced fracture cleavage. It subparallels the dominant schistosity in spatially associated mafic volcanic and volcano-sedimentary rocks.

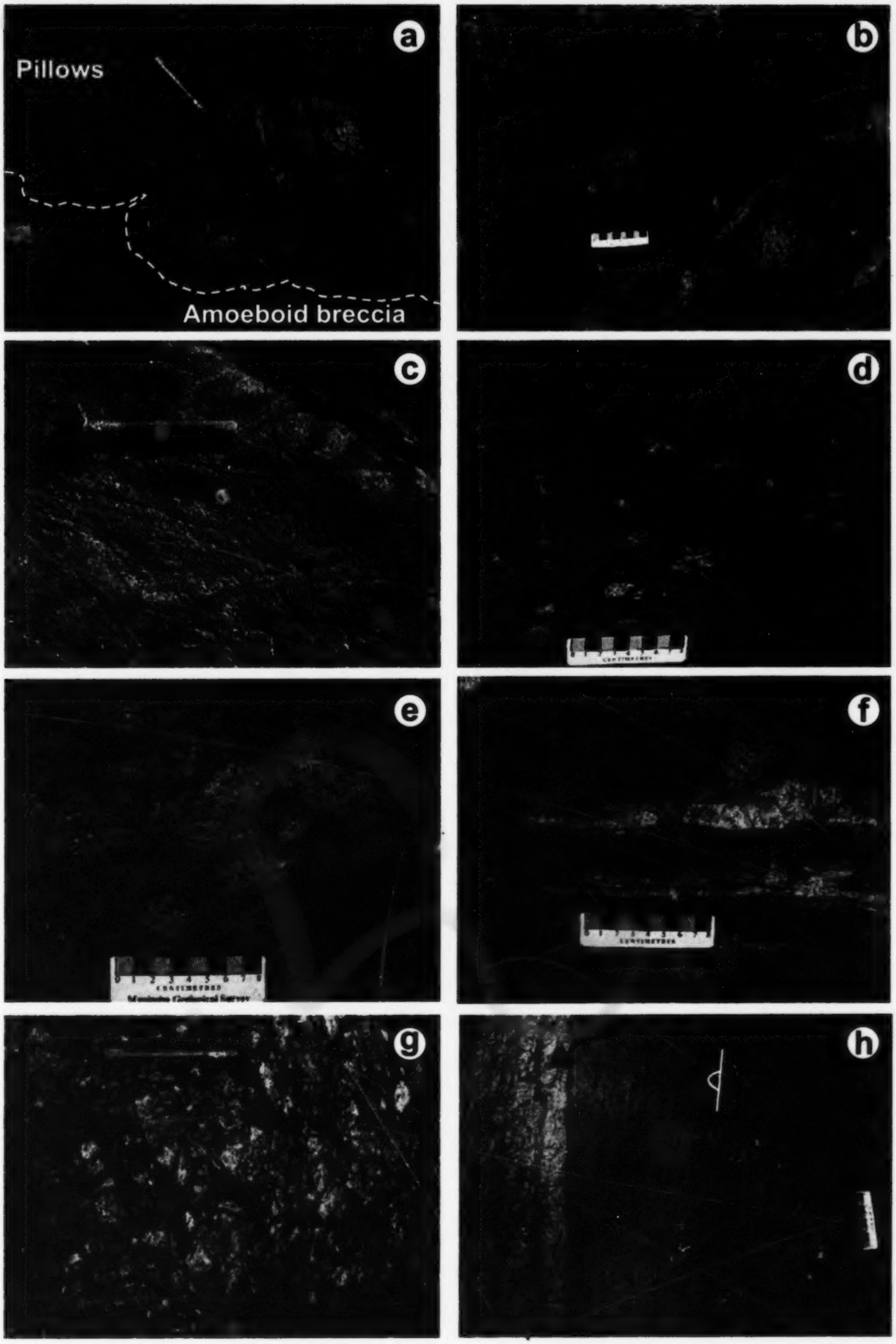
a
Pillows
Amoeboid breccia
b
c
d
CENTIMETRES
e
0 1 2 3 4 5 6 7 8
CENTIMETRES
Manitoba Geological Survey
f
CENTIMETRES
g
h

Figure GS-2-5: *Photographs of various units of the Hook Lake Block:* ***a)*** *syngenetic hydrothermal quartz-epidote alteration in aphyric pillowed flows, with hammer for scale;* ***b)*** *centimetre-scale concentric zoning in aphyric pillows;* ***c)*** *plagioclase- and pyroxene-phyric pillow basalt;* ***d)*** *heterolithic, clast-supported, mafic–felsic volcanic breccia;* ***e)*** *monolithic plagioclase- and pyroxene-phyric volcanic breccia;* ***f)*** *bedded fine-grained tuff (bottom) and scoriaceous lapilli tuff (top);* ***g)*** in situ *brecciation of massive rhyolite by iron-carbonate alteration; and* ***h)*** *graded bedding in reworked volcanic rocks, with tops to the west.*

Plagioclase- and pyroxene-phyric basalt

Plagioclase- and pyroxene-phyric pillowed basalt flows weather buff-beige to brown and has dark green to grey fresh surfaces. Pillows range in size from 0.1 to 2 m, and average size varies across stratigraphy, generally decreasing towards the top of flows. Stubby to equant pyroxene phenocrysts (10–15%), 2–6 mm in diameter, are the most distinctive feature of this rock. Fine-grained plagioclase phenocrysts, 0.5–3 mm in diameter, constitute 10–15% of the basalt. Pillow selvages are typically thin (0.5 cm) but locally increase in thickness up to 2 cm. Pillows are closely packed and contain very minor interpillow material. Where observed, interpillow material consists of epidotized and weakly to moderately silicified hyaloclastic material. Quartz-filled amygdules and gas cavities (5–20%), locally reaching 6 cm in size, occur in the majority of pillows and are concentrated around the rims of individual pillows *(*Figure GS-2-5c*)*. Amygdules show a general increase in size and abundance towards the top of flows. Southwest-younging topping directions, based on pillow forms and flow architecture, can be determined with confidence where clean exposures exist. Eyebrow structures with recessive filling were observed at one outcrop and displayed tops consistent with those derived from pillow forms. Because they are parallel to, and may be related to, a prominent fracture set, care must be taken in their interpretation.

Amoeboid pillow breccia, which locally contains up to 20% epidotized matrix, is gradational with pillowed basaltic flows. At some locations west of Highway 10, where amoeboid pillow breccia forms traceable units that stratigraphically overlie pillowed basalt, it is interpreted to represent the tops of flows. In an excellent exposure east of Mud Lake, however, amoeboid pillow breccia occurs as irregular, discontinuous zones within a coherent pillowed flow, and its relationship to the pillowed portion is not clear.

Volcaniclastic rocks

Monolithic to heterolithic mafic to mafic–felsic breccia

Reworked volcanic rocks (Figure GS-2-5d) intercalated with plagioclase- and pyroxene-phyric basalt occur predominantly, but not exclusively, in a basin towards the top of the western sequence. Their weathered and fresh surfaces are similar to those of the underlying volcanic flows. The basal unit consists of clast- to locally matrix-supported, poorly sorted, heterolithic mafic–felsic breccia. Clasts range from 2–100 cm in size and include quartz-feldspar–amygdaloïdal aphyric, plagioclase-phyric, and plagioclase-pyroxene–phyric basalt; mafic scoriaceous lapilli; and feldspar±quartz–phyric rhyolite. Felsic clasts are generally slightly larger than mafic types and show greater angularity.

In the south, this unit is intercalated with plagioclase-pyroxene–phyric basalt flows. Where the breccia immediately overlies these flows, it contains clasts that are almost exclusively (95%) subangular to rounded plagioclase-pyroxene–phyric basalt. They range in size from 2 to 30 cm and contain varying amounts of quartz- and feldspar-filled amygdules *(*Figure GS-2-5e*)*. The remaining quartz- and feldspar-phyric rhyolite clasts (5%) are angular to subangular and 5–50 cm in diameter, and contain quartz 'eyes' up to 0.5 cm in size. Gradational changes in the breccia occur upsection. Fragments of aphyric basalt, moderately to strongly feldspar-phyric basalt with 15–20%, 2–5 mm plagioclase phenocrysts, and highly vesicular mafic scoriaceous lapilli <5 cm in size begin to appear in abundance. The average size of the clast population decreases upsection to less than 10 cm, the proportion of felsic clasts increases to approximately 20%, and the amount of matrix increases to a maximum of 15–20%. Bedded tuff and scoriaceous lapilli tuff are locally present throughout the section (Figure GS-2-5f).

In the north, similar breccia units are observed with a slightly different 'stratigraphy'. Heterolithic mafic–felsic breccia dominates the base of the basin, with 5–20% angular to subangular, 2–40 cm clasts of aphyric to slightly porphyritic rhyolite mixed with a variety of subrounded, 0.5–25 cm mafic clasts (highly amygdaloidal aphyric basalt, plagioclase-phyric basalt and plagioclase-pyroxene–phyric basalt). These heterolithic mafic–felsic breccia units are locally intercalated with heterolithic mafic breccia, with sharp bedding contacts locally developed.

The matrix of volcaniclastic breccia in the western sequence is composed of chlorite±actinolite, with varying amounts of plagioclase (±pyroxene) crystals and crystal fragments. The matrix typically displays a pronounced anastomosing foliation. Primary sedimentary features are rare in volcaniclastic units of the western sequence and, as a result, reliable top determinations are scarce.

Eastern sequence

The eastern sequence is characterized by the absence of mafic volcanic flows in the stratigraphy. It is dominated by a sequence of reworked volcanic rocks interlayered with aphyric to quartz- and feldspar-phyric rhyolite flows.

West of Manistikwan Lake, rhyolite similar in appearance to rhyolite observed within the western sequence occurs in abundance. It outcrops as both laterally continuous layers and irregular discontinuous lobes. Basal massive rhyolitic flows, which weather white and have blue-grey fresh surfaces, are typically aphyric or contain 5–10%, 2–5 mm quartz and feldspar phenocrysts. Massive rhyolite is typically capped by monolithic felsic breccia and locally overlain by well-bedded, fine- to very fine grained felsic tuff. Felsic breccia is clast supported, with a general increase in the amount of matrix and decrease in the size of clasts upsection. Matrix material is primarily chlorite±sericite and is sometimes highly silicified. At one location southeast of the Cliff Lake pluton in an otherwise massive quartz-phyric rhyolite, a narrow zone of intense iron-carbonate alteration has formed an *in situ* pseudobreccia (Figure GS-2-5g).

Reworked volcanic rocks in the eastern sequence consist of monolithic aphyric basalt breccia, heterolithic mafic lapilli tuff to breccia, heterolithic mafic–felsic breccia and minor laminated mafic and felsic tuff. Volcanic breccia is clast to matrix supported and shows variations in clast size and clast population across section. Bedding is readily observed throughout the eastern sequence and can occasionally be used for reliable top determinations (Figure GS-2-5h). Two small outcrops of interbedded pebble conglomerate, greywacke and laminated siltstone were observed on the western shore of Manistikwan Lake, but they could not be traced due to large gabbroic intrusions in the vicinity.

Intrusive rocks

Several generations of mafic and felsic intrusions crosscut all rock types within the stratigraphy of the Hook Lake Block. The most abundant intrusive phase consists of numerous mafic dikes trending northwest to north-northwest. Mafic dikes are ubiquitous throughout the stratigraphy, in some cases forming more than 80% of outcrop. There is abundant variation in the texture and mineralogy of mafic dikes, including 1) plagioclase- and pyroxene-phyric dikes containing up to 60% plagioclase and pyroxene phenocrysts, which are 2–4 mm near dike margins and increase to >1 cm in the centre; 2) aphanitic to very fine grained basaltic dikes, with locally compound margins; and 3) feldspar-phyric dikes of intermediate composition, with 25%, 3–6 mm euhedral feldspar phenocrysts concentrated towards their centres. Larger equivalents of these dikes east of the northwest arm of Schist Lake and west of Manistikwan Lake include fine-grained, equigranular, oikocrystic and plagioclase-glomeroporphyritic gabbroic phases (Figure GS-2-6a, b). Minor shearing is localized along the contacts of some dikes.

Numerous aphyric to feldspar-phyric rhyolite dikes and domes occur throughout the Hook Lake Block. Narrow dikes generally trend north and typically crosscut mafic dikes and dike swarms. Larger lenticular to irregular rhyolite intrusions with numerous offshoots (<3 m in width) occur west of Manistikwan Lake, east of Mud Lake, west of the Cliff Lake pluton and surrounding the southern segment of the Cliff Lake pluton.

The northeastern portion of the map area is dominated by the Cliff Lake plutonic complex. The Cliff Lake pluton is very well exposed and forms a prominent topographic high in the area. The majority of the Cliff Lake pluton is composed of medium- to coarse-grained, quartz-phyric tonalite with 30%, 0.5–1 cm quartz phenocrysts. Quartz diorite phases are abundant along the western and southern edges. The margins of the Cliff Lake pluton are characterized by abundant xenoliths of mafic volcanic rocks (locally up to 75%). Xenoliths range from less than 0.1 m to many tens of metres in size, display baked margins and are locally partially resorbed. Primary volcanic features are well preserved in larger xenoliths (Figure GS-2-6c, d). Features in volcanic rocks adjacent to the Cliff Lake pluton to the west and south have been overprinted and homogenized by recrystallization due to the thermal effects of the intruding body (contact metamorphism?).

A small intrusion of melagabbro norite southwest of the Cliff Lake pluton is coarse- to very coarse grained. It displays a 'knobby' texture and contains 60% clinopyroxene (0.5–2 cm), 20% orthopyroxene and 20% interstitial anhedral plagioclase (Figure GS-2-6e).

Structural geology and kinematics

The dominant structural features in the map area are the north- to northwest-trending, block-bounding Cliff Lake and Manistikwan Lake faults. The Manistikwan Lake Fault is located just off the western shore of Manistikwan Lake and not exposed in the map area. The Cliff Lake Fault is similarly hidden, although an excellent exposure occurs in a quarry just east of Highway 10 prior to the Flin Flon turn-off. The Cliff Lake Fault, which trends north-northwest, is approximately 15 m wide at its maximum and juxtaposes volcanic and volcaniclastic rocks of the Hook Lake Block to the east with fluvial sedimentary rocks of the Missi Group to the west. Close examination of the Cliff Lake Fault indicates two generations of movement. The dominant, early movement forms a pervasive mylonitic ductile foliation with well-developed dextral S-C fabrics (Figure GS-2-6f). This early fabric is overprinted by multiple sets of small-scale conjugate kink bands with steep axes, consistent with shortening subparallel to the trend of the fault. The early mylonitic fabric is further crosscut by coincident quartz-chlorite–filled tension-gash structures with associated pyrite plus minor chalcopyrite mineralization. The tension gashes are at an angle of 10–15° counterclockwise and locally offset by sinistral shear bands subparallel to the tension gashes. The strain gradient into the Cliff Lake Fault is very sharp. Immediately west, approximately 3 m beyond the fault margin, polymictic conglomerate of the Missi Group shows only weak deformation and no evidence of shearing.

Numerous ductile-brittle splays, 0.5–5 m wide, emanating from the Cliff Lake Fault truncate and disrupt the stratigraphy of the Hook Lake Block in the map area. Kinematic indicators are sparse along these subsidiary structures but, where noted, show both dextral and sinistral shear sense (Figure GS-2-6g, h). It is currently unclear whether the deformation history of these structures is akin to that noted in the Cliff Lake Fault (i.e., early dextral followed by minor sinistral reactivation).

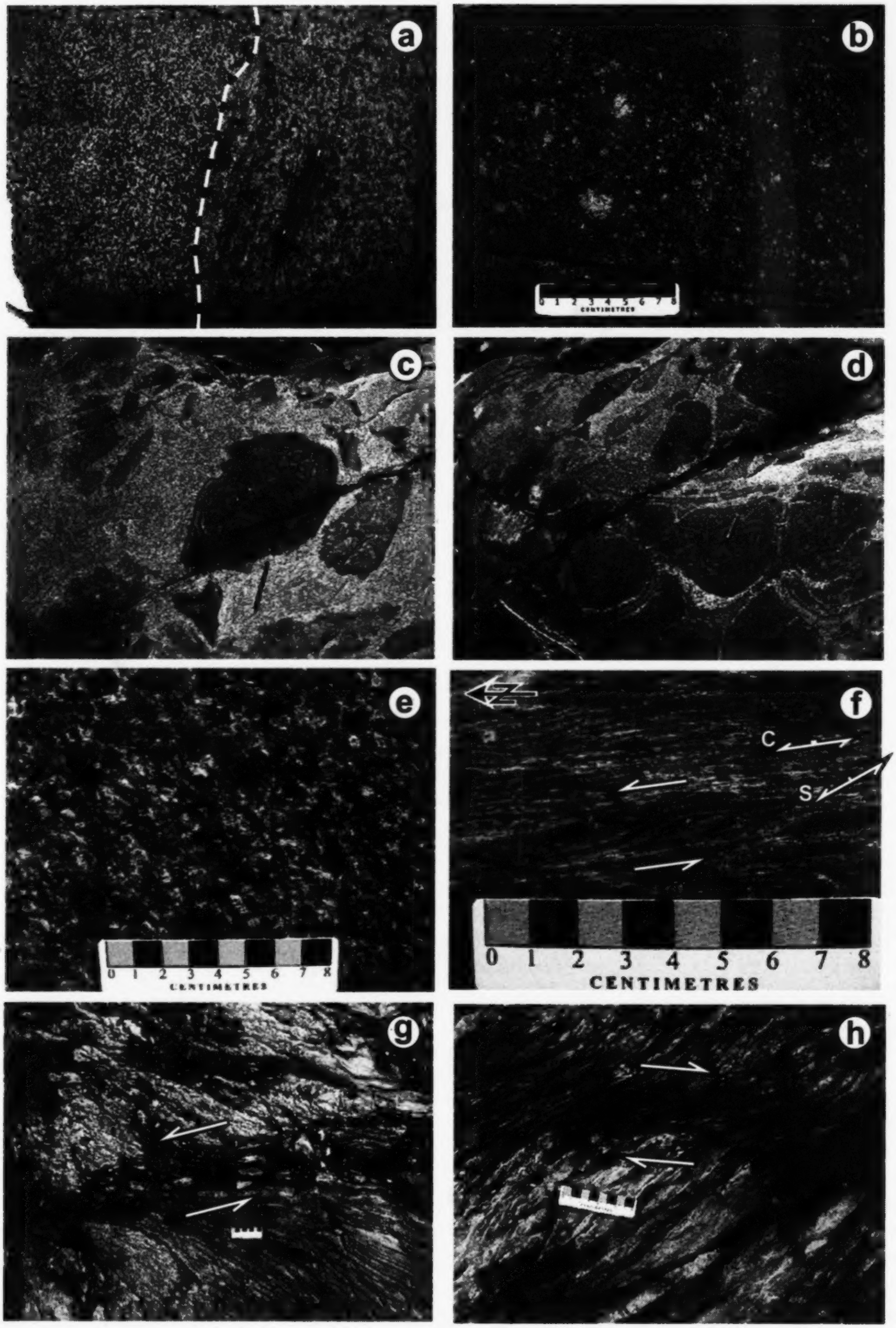

Figure GS-2-6: *Photographs of various intrusive and structural relationships in the Hook Lake Block:* ***a)*** *intrusive contact between pyroxene-phyric (left) and oikocrystic gabbro (right), with pen magnet for scale;* ***b)*** *plagioclase-glomeroporphyritic gabbro;* ***c)*** *xenoliths of aphyric pillow basalt in the Cliff Lake pluton, with pencil for scale;* ***d)*** *large screen of pillow basalt intruded by tonalite–quartz diorite of the Cliff Lake pluton, with pencil for scale;* ***e)*** *knobby-textured melagabbro norite west of the Cliff Lake pluton;* ***f)*** *prominent dextral S-C fabric in the Cliff Lake Fault;* ***g)*** *narrow shear zone showing sinistral shear sense; and* ***h)*** *narrow shear zone showing dextral shear sense.*

The Hook Lake Fault trends northwest and separates the western and eastern sequences. It is consistent in appearance, orientation and kinematics with splays from the Cliff Lake Fault; however, it has not itself been traced directly into the Cliff Lake Fault.

Two foliations (local S_1 and S_2) occur throughout the Hook Lake Block rocks. The S_1 foliation is present in all volcanic and volcaniclastic rocks, trends between 320 and 355°, and is subparallel to the Cliff Lake Fault and its associated splays. The overprinting S_2 foliation, which is in the majority of outcrop, is generally oriented 10–20° clockwise to S_1. The orientation of the S_2 foliation is consistent with, and may be related to, a sinistral reactivation event on the Cliff Lake Fault. Further thin section analysis is pending to test this interpretation.

Despite the abundance of outcrop, good exposures of x-y foliation planes are rare, thus rendering the systematic collection of lineation data rather difficult. This is further hindered by the small angle separating the two dominant foliations. Where observed, stretching, mineral and intersection lineations show a consistent shallow to moderate southeast plunge. It is likely that multiple generations of subparallel lineations exist in the map area, but they currently cannot be assigned to a particular deformation event.

Discussion and economic considerations

The stratigraphy of the western sequence is very well documented and, up to Charlie Lake Fault, seems little affected by major structures west of the Cliff Lake plutonic complex. The thick sequence of mixed heterolithic breccia, both felsic and mafic, overlying the aphyric to sparsely feldspar-phyric basaltic flows is interpreted to represent proximal resedimentation of pre-existing mafic and felsic volcanic rocks into a subsidence structure and/or basin within the Hook Lake Block. The northern margin of this preserved basin seems to be marked by the mafic dike swarm with associated felsic dikes east of Grant Lake. This dike swarm, which traces eastward into the underlying mafic volcanic rocks stratigraphically beneath a large quartz-feldspar–phyric rhyolitic flow and breccia, is associated with gossanous mineralized zones (Figure GS-2-3). Grab samples from an old trench in the mineralized zone contain massive, thinly layered pyrrhotite and pyrite with minor chalcopyrite. Assay results are pending. Mafic flows immediately surrounding the trench show noteworthy quartz-epidote alteration patches, which are interpreted to have resulted from paleohydrothermal activity in this area.

The southern segment of the western sequence has been more substantially affected by deformation. The thick sequence of heterolithic breccia filling the subsidence basin has been dismembered by several north-northwest–trending splays off the Cliff Lake Fault, resulting in discontinuous screens of partial stratigraphic sections juxtaposed against one another. This is particularly prominent east of Mud Lake.

Narrow sulphide zones associated with the contact of gabbroic to fine-grained mafic dikes have been observed in a few locations throughout the western sequence. They mostly occur where mafic dikes crosscut massive felsic rocks. The observed mineralization consists of disseminated pyrrhotite (<5%) with some pyrite (<2%).

Very old trenches, along with recent drill pads, are located just north of the Channing Road turn-off in the swamp. Scattered outcrops of mafic breccia in this area contain well-developed gossan with disseminated pyrrhotite and minor pyrite (2–20%; Gale and Eccles, 1988).

Rocks of the eastern sequence are composed mainly of laterally continuous breccia layers with subordinate mafic flows. A significant proportion of the breccia is felsic in composition, or contains felsic as well as mafic clasts. The abundance of breccia, combined with a lack of flows, suggest that these rocks, similar to those of the western sequence, could represent proximal resedimentation of pre-existing felsic and mafic volcanic rocks into a subsidence structure and/or basin.

Rocks in the eastern sequence have been heavily explored for copper-zinc since the 1930s. Primary sulphide associated with rhyolite flows occurs as discontinuous lenses and lobes of disseminated (<10%), stringer to locally semimassive (20–30%) pyrite±pyrrhotite, sphalerite and chalcopyrite. Mineralization occurs either at the contact between massive and fragmental rhyolite flows, within fragmental rhyolite or between fragmental rhyolite and overlying volcanic-volcaniclastic rocks. An example of the latter occurs approximately 300 m west of Manistikwan Lake, just south of the Cliff Lake plutonic complex. This sulphide occurrence has been previously documented (Gale and Eccles, 1988, occurrence 61) and been the focus of drilling by Hudson Bay Exploration and Development Co. Ltd. in the early 1980s. Parts of the zone have prominent sphalerite mineralization, with assays up to 12% Zn reported by Gale and Eccles (1988). The association of mineralization with the fragmental rhyolite flows suggests potential for volcanogenic massive sulphide–type mineralization in the area (Gale and Eccles, 1988).

Remobilized sulphide has been observed in and close to the Cliff Lake Fault and associated faults. The mineralizing event in the Cliff Lake Fault exposure at the quarry off Highway 10 can be correlated with the second (sinistral) movement along the fault, as evidenced by the presence of sulphide (pyrite±minor chalcopyrite) in association with crosscutting quartz-chlorite tension gashes. If larger or more strongly developed structures related to this deformation event are present elsewhere in the region or even the belt, they could represent future exploration targets.

Overall, recent mapping in the Hook Lake Block has highlighted many similarities between these rocks and those of the neighbouring Flin Flon Block. Both blocks contain volcanic stratigraphy displaying significant subsidence and/or basin structures with associated felsic volcanism plus or minus VMS-type mineralization. However, a direct assessment of the potential link between the western or eastern stratigraphy of the Hook Lake Block and that of the Flin Flon Block is still premature. Heterolithic breccia sequences and felsic volcanic rocks, which are similar to those found in the Flin Flon Block spatially associated with the Flin Flon–Callinan–Triple 7 mines (Figure GS-2-2; Bailes and Syme, 1989; Devine, 2003; DeWolfe and Gibson, 2006) and the Schist and Mandy VMS deposits (Figure GS-2-2; Bailes and Syme, 1989; Simard, 2006; Simard, GS-1, this volume; Cole et al., GS-3, this volume), are found in the map area. However, further analytical work (geochemistry, isotopes and geochronology) is required before a more complete comparison with the ore-hosting sequences at Flin Flon and Schist Lake can be made.

Acknowledgments

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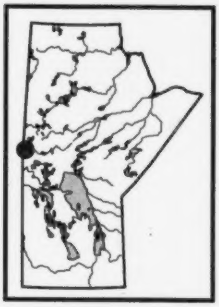
GS-3 Preliminary description of the lithofacies and structure of the Schist Lake mine area, Flin Flon, Manitoba (part of NTS 63K12)

by E.M. Cole[1], H.L. Gibson[1] and B. Lafrance[1]



Cole, E.M., Gibson, H.L. and Lafrance, B. 2007: Preliminary description of the lithofacies and structure of the Schist Lake mine area, Flin Flon, Manitoba (part of NTS 63K12); *in* Report of Activities 2007, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 33–42.

Summary

The goal of this two-year research project is to characterize and describe the Schist Lake and Mandy volcanogenic massive sulphide (VMS) deposits and their hostrocks. A further objective is to determine if these VMS deposits are time stratigraphic equivalent to those occurring in the main Flin Flon camp. The first year of this two-year project focused on the Schist Lake mine area, where detailed lithofacies and alteration-facies maps were completed, along with detailed field descriptions of each lithofacies. The mine is hosted by a succession of mafic and felsic volcaniclastic rocks that were deposited in a submarine basin. The rocks are strongly deformed throughout the map area, although there is a marked increase in deformation close to a north-northwest–trending sinistral shear zone that divides the peninsula on which the mines occur into eastern and western blocks. Within this shear zone, the Schist Lake orebody occurs as a series of ore lenses that plunge steeply to the east, parallel to a strong lineation. The distribution of the chlorite alteration facies suggests that the eastern block is part of the footwall to the Schist Lake deposit, whereas the small localized patches of iron staining and sericite alteration in the western block are consistent with the latter alteration being part of the hangingwall to the deposit. However, given the unknown amount of displacement within the shear zone, alteration facies in the western block may be unrelated to the Schist Lake deposit.

Introduction

The Flin Flon district, which lies within the Paleoproterozoic Flin Flon Belt, is well known for its volcanogenic massive sulphide deposits. Six current (Callinan, Triple 7 and Trout Lake) and past-producing (Flin Flon, Mandy and Schist Lake) VMS deposits occur in the immediate vicinity of the town of Flin Flon, which makes this area one of the most productive base-metal districts in Canada. Recent detailed regional mapping in the Flin Flon area, carried out under the Targeted Geoscience Initiative (MacLachlan, 2006; Simard, 2006) and as research funded by the Natural Sciences and Engineering Research Council of Canada (NSERC; Devine et al., 2002; DeWolfe and Gibson, 2006), is designed to better characterize the camp stratigraphy and structure. The relationship between the Callinan–Triple 7–Flin Flon and the Schist Lake–Mandy deposits remains unresolved and is an important question. The object of this research is to document the volcanic and structural setting of the Schist Lake and Mandy deposits, record the alteration types associated with these deposits and, ultimately, assess the viability of correlating the Schist Lake–Mandy deposits with the Callinan–Triple 7–Flin Flon deposits.

Regional geology

The Paleoproterozoic Trans-Hudson Orogen (THO) is a collisional belt that extends from South Dakota through Saskatchewan, Manitoba and northern Quebec into Greenland (Figure GS-3-1). It formed during the collision of two Archean cratons, the Superior craton to the east and the Rae-Hearne craton to the west, at 1830–1800 Ma (Hoffman, 1988; Lewry and Collerson, 1990; Lewry et al., 1994; Corrigan et al., 2005).

The Flin Flon Belt has been subdivided into four main tectonostratigraphic assemblages that formed at ca. 1.90 Ga: isotopically juvenile oceanic arc, ocean floor, oceanic plateau–ocean island and isotopically evolved oceanic arc (Syme, 1990; Syme and Bailes, 1993; Stern et al., 1995). Volcanic rocks in the Flin Flon area are part of a ca. 1903 Ma juvenile arc assemblage (Syme et al., 1999), consisting mostly of subaqueous mafic rocks with associated volcaniclastic deposits and minor felsic flow and volcaniclastic rocks (Bailes and Syme, 1989). Juvenile arc assemblages host all 27 known volcanogenic massive sulphide deposits in the Flin Flon greenstone belt, including the Mandy and Schist Lake deposits.

Geology of the Schist Lake–Mandy area

The Schist Lake and Mandy mines are located 5 km southeast of the town of Flin Flon (Figure GS-3-2). The first comprehensive map of the area, completed by C.H. Stockwell in the 1940s (Stockwell, 1960), subdivided the volcanic rocks hosting the Schist Lake and Mandy deposits into andesite, basalt, dacite, dacite flow breccia, andesite breccia, quartz porphyry and quartz porphyry breccia. The rocks generally strike northwest and dip steeply to the east. Cairns et al. (1957) studied the Schist Lake and Mandy deposits, and suggested that they are hosted along strike from one another within a sericite carbonate schist, derived from a fine-grained, grey, quartz

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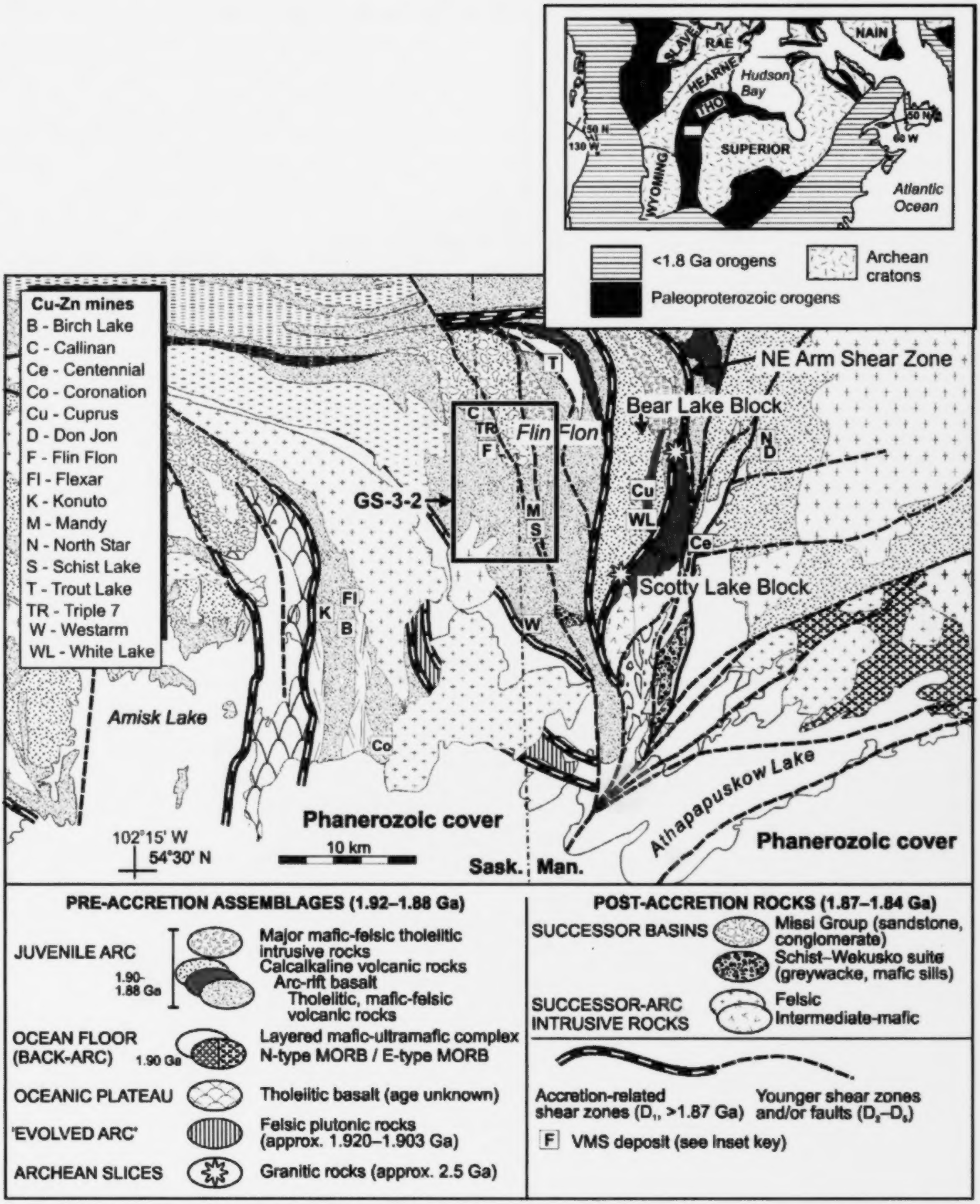
RAE
SLAVE
HEARNE
NAIN
Hudson Bay
THO
SUPERIOR
WYOMING
60 N
130 W
50 N
60 W
Atlantic Ocean
<1.8 Ga orogens
Archean cratons
Paleoproterozoic orogens
Cu-Zn mines
B - Birch Lake
C - Callinan
Ce - Centennial
Co - Coronation
Cu - Cuprus
D - Don Jon
F - Flin Flon
Fl - Flexar
K - Konuto
M - Mandy
N - North Star
S - Schist Lake
T - Trout Lake
TR - Triple 7
W - Westarm
WL - White Lake
NE Arm Shear Zone
Bear Lake Block
Flin Flon
GS-3-2
Scotty Lake Block
Amisk Lake
Athapapuskow Lake
Phanerozoic cover
Phanerozoic cover
102°15' W
54°30' N
10 km
Sask.
Man.
PRE-ACCRETION ASSEMBLAGES (1.92–1.88 Ga)
JUVENILE ARC
1.90-1.88 Ga
Major mafic-felsic tholeiitic intrusive rocks
Calcalkaline volcanic rocks
Arc-rift basalt
Tholeiitic, mafic-felsic volcanic rocks
OCEAN FLOOR (BACK-ARC)
1.90 Ga
Layered mafic-ultramafic complex
N-type MORB / E-type MORB
OCEANIC PLATEAU
Tholeiitic basalt (age unknown)
'EVOLVED ARC'
Felsic plutonic rocks (approx. 1.920–1.903 Ga)
ARCHEAN SLICES
Granitic rocks (approx. 2.5 Ga)
POST-ACCRETION ROCKS (1.87–1.84 Ga)
SUCCESSOR BASINS
Missi Group (sandstone, conglomerate)
Schist-Wekusko suite (greywacke, mafic sills)
SUCCESSOR-ARC INTRUSIVE ROCKS
Felsic
Intermediate-mafic
Accretion-related shear zones (D₁, >1.87 Ga)
Younger shear zones and/or faults (D₂–D₅)
F VMS deposit (see inset key)

Figure GS-3-1: *Geology of the Flin Flon Belt, showing locations of known volcanogenic massive sulphide (VMS) deposits (modified from Syme et al., 1999); box indicates the area covered by Figure GS-3-2; inset map shows the location of the Flin Flon Belt within the Trans-Hudson Orogen (THO).*

porphyry. Level plans and sections of the Schist Lake mine, compiled and interpreted when the mine was in production from 1954 to 1976, show the orebodies occurring within a quartz porphyry unit and localized sericite schist (Cotter, 1969). Bailes and Syme (1989) further refined the mine stratigraphy and linked the deposits to a heterolithic felsic volcanic breccia that is strongly chloritized, silicified, pyritized and foliated near the orebodies.

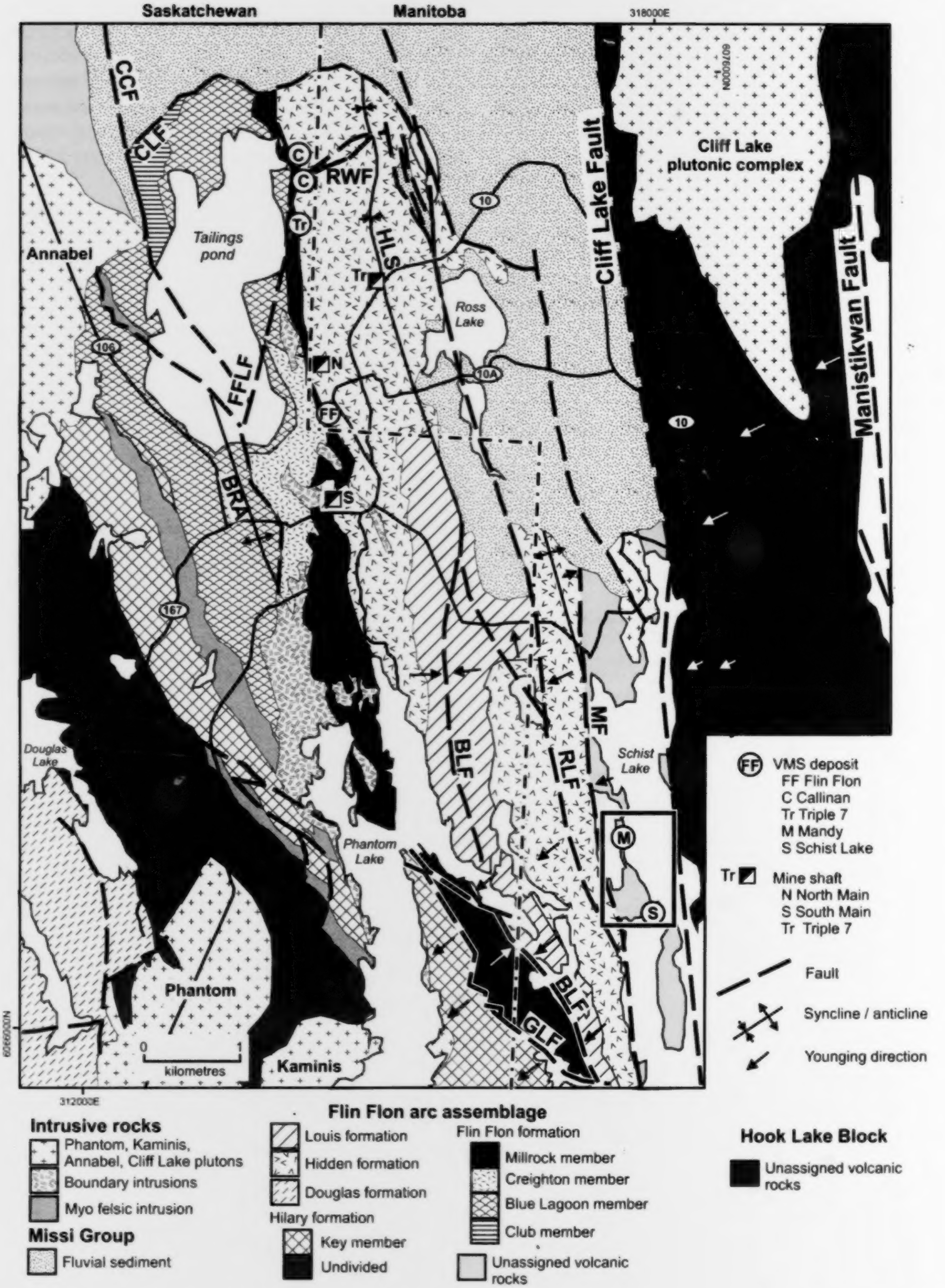
Saskatchewan
Manitoba
318000E
6076000N
CCF
CLF
C
C
RWF
Tr
HLS
Tr
Cliff Lake Fault
Cliff Lake plutonic complex
10
Manistikwan Fault
Tailings pond
Annabel
106
Ross Lake
N
10A
FFLF
FF
10
BRA
S
167
MF
BLF
RLF
Schist Lake
Douglas Lake
Phantom Lake
M
S
BLF
GLF
Phantom
Kaminis
0
1
kilometres
6066000N
312000E
VMS deposit
FF Flin Flon
C Callinan
Tr Triple 7
M Mandy
S Schist Lake
Mine shaft
N North Main
S South Main
Tr Triple 7
Fault
Syncline / anticline
Younging direction
Intrusive rocks
Phantom, Kaminis, Annabel, Cliff Lake plutons
Boundary intrusions
Myo felsic intrusion
Missi Group
Fluvial sediment
Flin Flon arc assemblage
Louis formation
Hidden formation
Douglas formation
Hilary formation
Key member
Undivided
Flin Flon formation
Millrock member
Creighton member
Blue Lagoon member
Club member
Unassigned volcanic rocks
Hook Lake Block
Unassigned volcanic rocks

Figure GS-3-2: *Simplified geology of the Flin Flon area, showing the major structures; box indicates the location of the Schist Lake–Mandy mines area (*modified from *Simard. 2006). Abbreviations: BLF, Burley Lake Fault; BRA, Beaver Road anticline; CCF, Creighton Creek Fault; CLF, Cliff Lake Fault; FFLF, Flin Flon Lake Fault; GLF, Green Lake Fault; HLS, Hidden Lake syncline; MF, Mandy Road Fault; RF, Rio Fault; RLF, Ross Lake Fault; RWF, Railway Fault.*

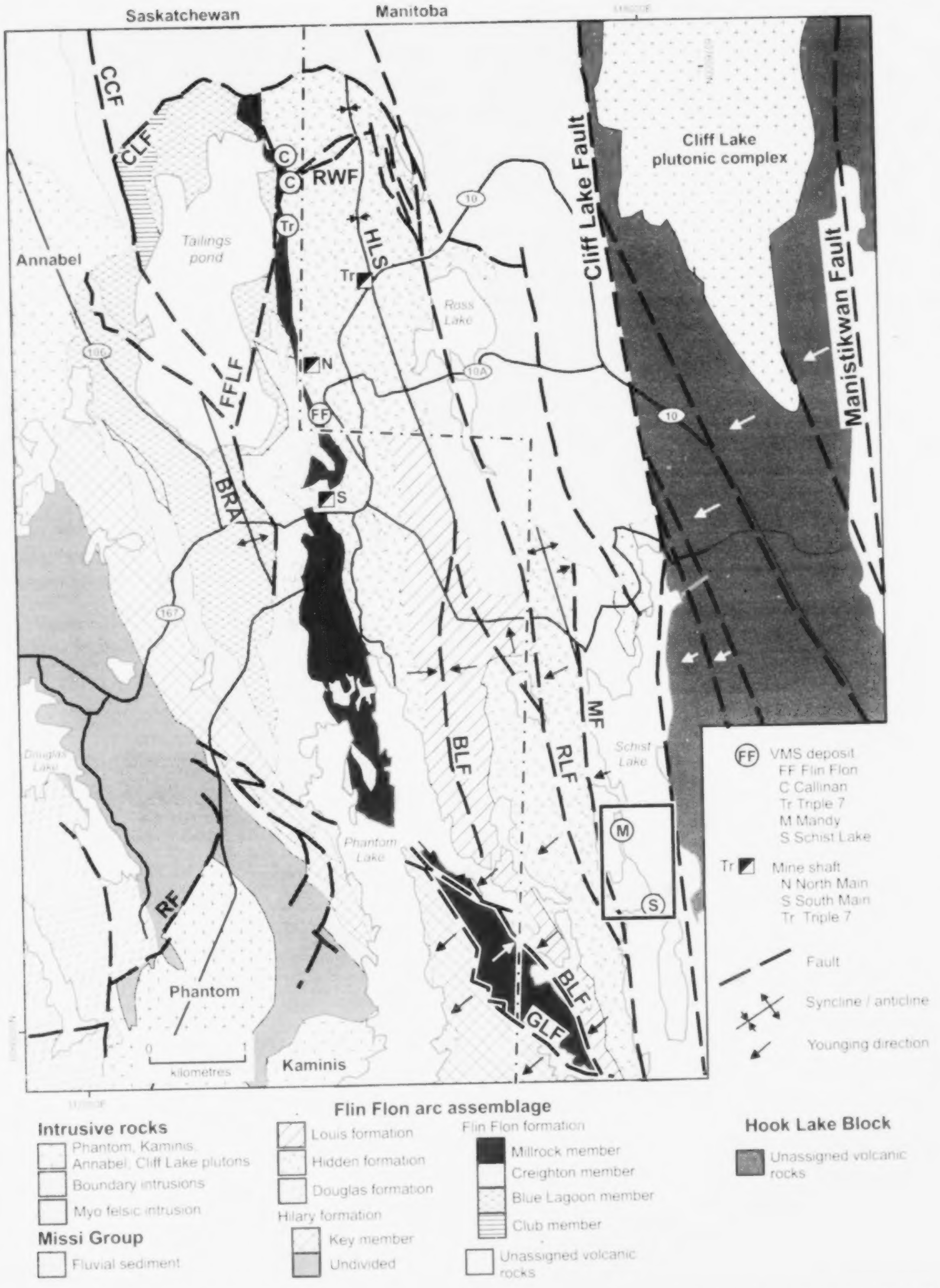
Saskatchewan
Manitoba
CCF
CLF
RWF
HLS
FFLF
BRA
Annabel
Tailings pond
Ross Lake
Cliff Lake Fault
Cliff Lake plutonic complex
Manistikwan Fault
10
10A
106
167
BLF
RLF
MF
GLF
RF
Schist Lake
Douglas Lake
Phantom Lake
Phantom
Kaminis
0
1
kilometres
C
Tr
N
FF
S
M
VMS deposit
FF Flin Flon
C Callinan
Tr Triple 7
M Mandy
S Schist Lake
Mine shaft
N North Main
S South Main
Tr Triple 7
Fault
Syncline / anticline
Younging direction
Intrusive rocks
Phantom, Kaminis, Annabel, Cliff Lake plutons
Boundary intrusions
Myo felsic intrusion
Missi Group
Fluvial sediment
Flin Flon arc assemblage
Louis formation
Hidden formation
Douglas formation
Hilary formation
Key member
Undivided
Flin Flon formation
Millrock member
Creighton member
Blue Lagoon member
Club member
Unassigned volcanic rocks
Hook Lake Block
Unassigned volcanic rocks

Figure GS-3-2: Simplified geology of the Flin Flon area, showing the major structures; box indicates the location of the Schist Lake–Mandy mines area (modified from Simard, 2006). Abbreviations: BLF, Burley Lake Fault; BRA, Beaver Road anticline; CCF, Creighton Creek Fault; CLF, Cliff Lake Fault; FFLF, Flin Flon Lake Fault; GLF, Green Lake Fault; HLS, Hidden Lake syncline; MF, Mandy Road Fault; RF, Rio Fault; RLF, Ross Lake Fault; RWF, Railway Fault.

Price (Hudson Bay Exploration and Development Co. Ltd. [HBED], internal report, 1971) determined that the rocks in the Schist Lake area display two prominent foliations and a strong lineation; the foliations strike 330° and 360°, and dip steeply to the east. The pronounced stretching lineation, observed in elongated fragments and amygdules, plunges 40–50° to the south, parallel to the plunge of the Schist Lake orebody (Cotter, 1969). Price (HBED, internal report, 1971) noted that the foliation is the strongest structural element in the Schist Lake–Mandy area and that it could be an axial-planar cleavage related to the Mandy Road anticline; the intensity of the foliation is variable. Bailes and Syme (1989) considered the Schist Lake–Mandy area to occur within a fault-bounded block.

Historical review of the Schist Lake and Mandy mines

The Mandy mine was the first mine in the Flin Flon area. It was discovered in 1915 by two prospectors, S.S. Reynolds and F.C. Jackson, and was brought into production in 1916 by Hudson Bay Mining and Smelting Co. Ltd. The open pit operation closed in 1919, to be reopened temporarily in 1943, until finally being closed in 1944. During these periods of operation, 125 000 tonnes of ore grading 8.22% copper and 11.38% zinc were extracted (Gilmore, 2000). The Mandy orebody consisted of several zones: an inner core rich in chalcopyrite, surrounded by a sphalerite-rich zone of mixed sulphide, and an outer zone dominated by pyrite (Bailes and Syme, 1989). Only the chalcopyrite-rich zone was mined. The orebody was 30 m long and 4 m wide, and extended to a depth of 10 m (Bailes and Syme, 1989). The ore lenses were elongate parallel to the strike of the foliation and dipped steeply to the east (HBED, internal report, 1971). The orebody was reported to contain gold and silver (Bruce, 1918).

The Schist Lake mine was an underground mine that produced 1.88 million tonnes grading 4.21% copper and 7% zinc from 1954 until 1976 (Gilmore, 2002). The orebody consisted of two main zones, each composed of several lenses (Figure GS-3-3; HBED archive data). The north zone contained three ore lenses with a maximum size of 60 m by 300 m, whereas the south zone contained four lenses that ranged from 60–120 m in length and 300–600 m in depth (Figure GS-3-3; HBED archive data). Howkins and Martin (1970) suggested that the four lenses of the south zone may have been part of one sulphide lens that was segmented by faults. The orebody contained a

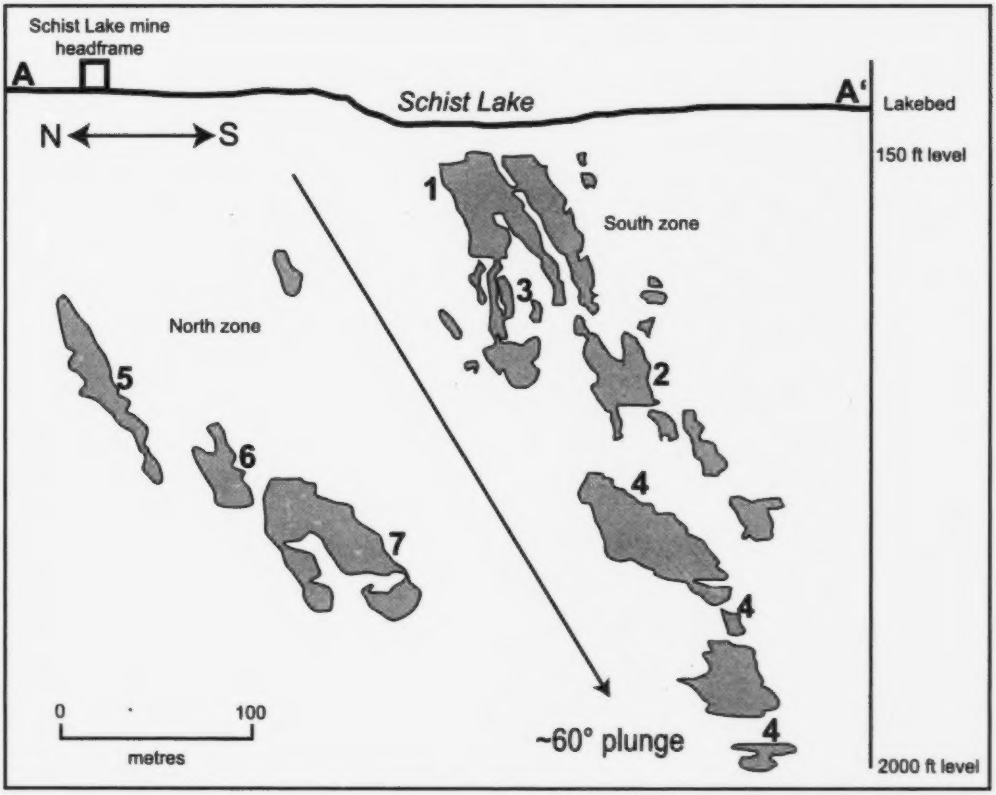

__Figure GS-3-3:__ Schematic section of the Schist Lake orebody (from Hudson Bay Exploration and Development Co. Ltd. archive data). Numbers 1–4 represent the ore lenses in the south zone and numbers 5–7 represent the ore lenses in the north zone. See Figure GS-3-4 for location of section.

pyrite-sphalerite-chalcopyrite assemblage with minor galena, but did not contain pyrrhotite (Bristol, 1974).

Geology of the Schist Lake mine area

The rocks of the Schist Lake mine area are generally well exposed along the east and west shores of the Schist Lake peninsula, with fewer outcrops in the forested areas in the middle of the peninsula (Figure GS-3-4). The volcanic strata have undergone significant deformation and are strongly foliated (*see* details below). The volcanic strata are strongly foliated and metamorphosed to the lower greenschist facies, containing a mineral assemblage dominated by chlorite, actinolite and albite, with localized epidote patches.

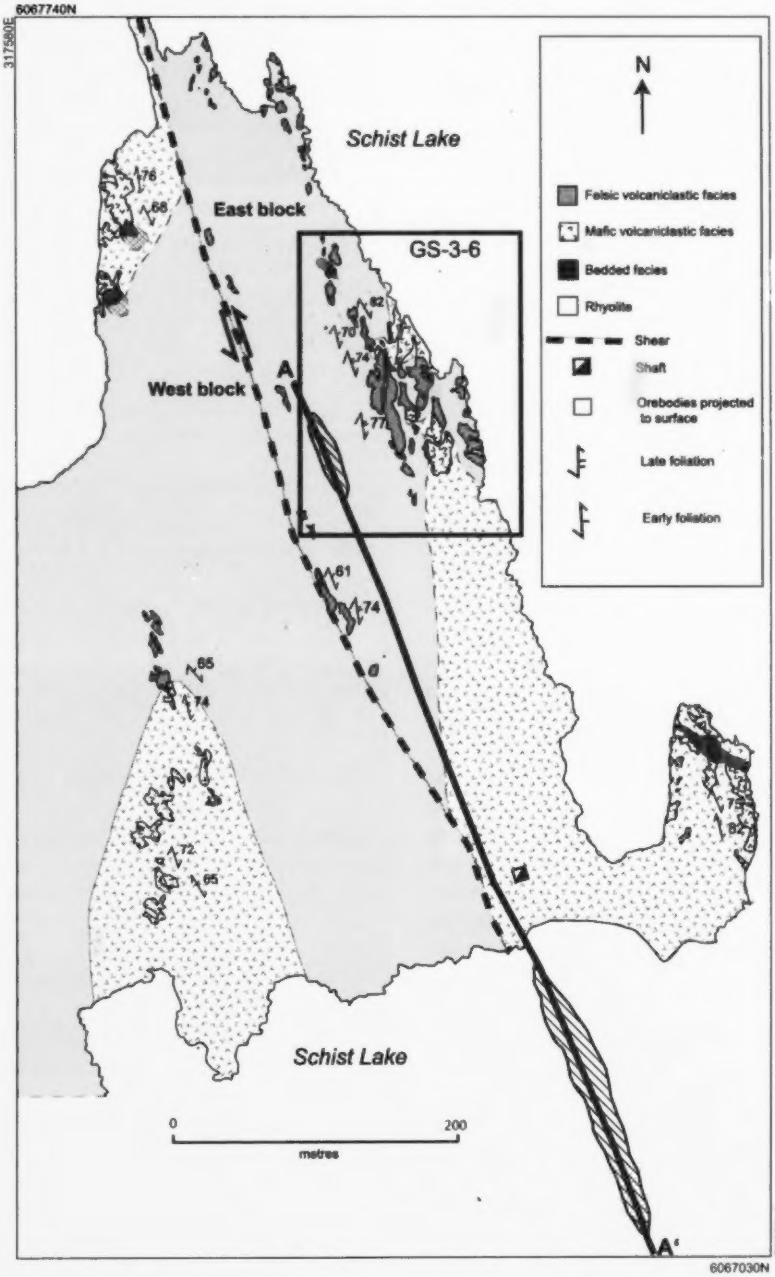
6067740N
317580E
N
Schist Lake
East block
West block
GS-3-6
A
A'
Felsic volcaniclastic facies
Mafic volcaniclastic facies
Bedded facies
Rhyolite
Shear
Shaft
Orebodies projected to surface
Late foliation
Early foliation
76
68
82
70
74
77
61
74
65
74
72
65
75
82
Schist Lake
0
200
metres
318080E
6067030N

Figure GS-3-4: Geology of the Schist Lake mine peninsula, including the surface projection of the orebody and the location of the shaft; box indicates the location of the alteration map (Figure GS-3-6). A–A' represents the line of section in Figure GS-3-3.

During this research, volcanic strata of the Schist Lake mine area were subdivided into 18 units that are grouped into three lithofacies types, based on their concentration of felsic and mafic clasts:

1) **mafic volcaniclastic facies:** a) clast-supported monolithic mafic volcaniclastic unit; b) matrix-supported monolithic mafic volcaniclastic unit; c) homogeneous mafic unit; d) heterolithic mafic volcaniclastic unit; e) clast-supported monolithic mafic volcaniclastic unit; f) heterolithic mafic volcaniclastic unit; g) massive crystal-rich mafic unit
2) **felsic volcaniclastic facies:** a) heterolithic felsic volcaniclastic unit; b) homogeneous sericitic felsic unit; c) felsic volcaniclastic unit with minor tuff beds; d) heterolithic felsic volcaniclastic unit; e) massive felsic unit; f) matrix-supported heterolithic felsic volcaniclastic unit
3) **bedded facies:** a) plagioclase-rich volcaniclastic unit with tuff beds; b) finely laminated tuff unit; c) massive mafic volcanic unit with tuff beds

Lithofacies descriptions

Mafic volcaniclastic facies

The mafic volcaniclastic facies consists of both heterolithic and monolithic mafic volcaniclastic rocks and a thin homogeneous mafic unit. It is characterized by breccia, composed mainly of mafic clasts in a mafic matrix. The breccia tends to be moderately to well sorted and can be both clast and matrix supported. The clasts range in size from 1 to 45 cm and include aphanitic mafic, plagioclase-porphyritic mafic and, locally, aphanitic felsic clasts. The aphanitic mafic clasts are grey on weathered surfaces and dark grey on fresh surfaces. They are homogeneous, subrounded to rounded, and contain up to 10% quartz-filled amygdules that range from 0.5 to 3 mm in diameter (Figure GS-3-5a). The plagioclase porphyritic clasts are homogeneous and subrounded, and contain 5–10% plagioclase phenocrysts ranging from 0.5 to 3 mm in size. They are pale grey on weathered surfaces and dark grey on fresh surfaces. The aphanitic felsic clasts are homogeneous and subrounded; they have a white weathered surface and a pale grey fresh surface. The matrix is very fine grained, mafic and, when not altered, dark brown-grey. Localized portions of the matrix display a mottled white and red-brown pattern; the white colour is possibly due to sericite alteration (*see* details below).

The thin, homogeneous mafic unit is brown-green when weathered and dark grey when fresh. It is very fine grained, aphanitic and aphyric. Where it is cut by a network of quartz veins, the mafic unit has pseudoclastic appearance. Although the presence of clasts is possible, they have not been observed. The mafic volcaniclastic facies has a maximum observed thickness of 60 m.

Felsic volcaniclastic facies

The felsic volcaniclastic facies consists of heterolithic volcaniclastic and massive felsic units. It is characterized by breccia composed mainly of felsic clasts in either a mafic or felsic matrix (Figure GS-3-5b). The breccia is moderately sorted and can be both clast and matrix supported. Clasts range in size from 1 to 35 cm and average 4 cm, and include aphanitic felsic, quartz-porphyritic felsic, amygdaloidal mafic and aphanitic mafic types. The aphanitic felsic clasts are homogeneous and subrounded; they have a whitish appearance when weathered and are pale grey when fresh. The quartz-porphyritic felsic clasts are homogeneous, subangular to subrounded and contain 10% quartz phenocrysts that range from 0.5 to 3 mm in size; they are white-grey on weathered surfaces and pale grey on fresh surfaces. The amygdaloidal mafic clasts are aphanitic and composed of 20% amygdules that are 4–6 mm in size. The aphanitic mafic clasts are homogeneous and subrounded, and contain 3% amygdules up to 2 mm in size. The matrix is very fine grained and can be either mafic or felsic in composition; further petrographic work is pending to assess the nature of the matrix.

The massive felsic unit is homogeneous and very fine grained. It is red-brown on weathered and grey on fresh surfaces. Locally, this unit is white and has a chalky texture, possibly due to sericite alteration (*see* details below). The felsic volcaniclastic facies has a maximum observed thickness of 120 m.

Bedded facies

The bedded tuff facies constitutes a very small portion of the Schist Lake mine area, where the tuff beds are intercalated with thicker volcaniclastic units.

The bedded tuff facies consists of fine laminations of coarse and fine material. The very fine grained beds tend to be only a few millimetres thick and are pale grey (Figure GS-3-5c). The coarse beds contain 25% plagioclase phenocrysts, 0.5–6 mm in size, and tend to be darker grey-pink. The bedded facies has a maximum observed thickness of 50 m.

Structural observations

Two foliations, defined by the alignment of chlorite and sericite and by the flattening of clasts, are present throughout the area. The main foliation strikes 340–360° and dips 70–85° east. It is overprinted by a second foliation that strikes 310–330° and dips 60–70° east. A stretching lineation, defined by the elongation of clasts (1:3 ratio) in the volcaniclastic rocks, trends 110–140° and plunges 55–65°. Both lineation and foliations are more intensely developed in a north-northwest–striking shear zone that transects the centre of the peninsula. The elongation of the clasts increases to a ratio of 1:6 within the shear zone. The second foliation shows an anticlockwise

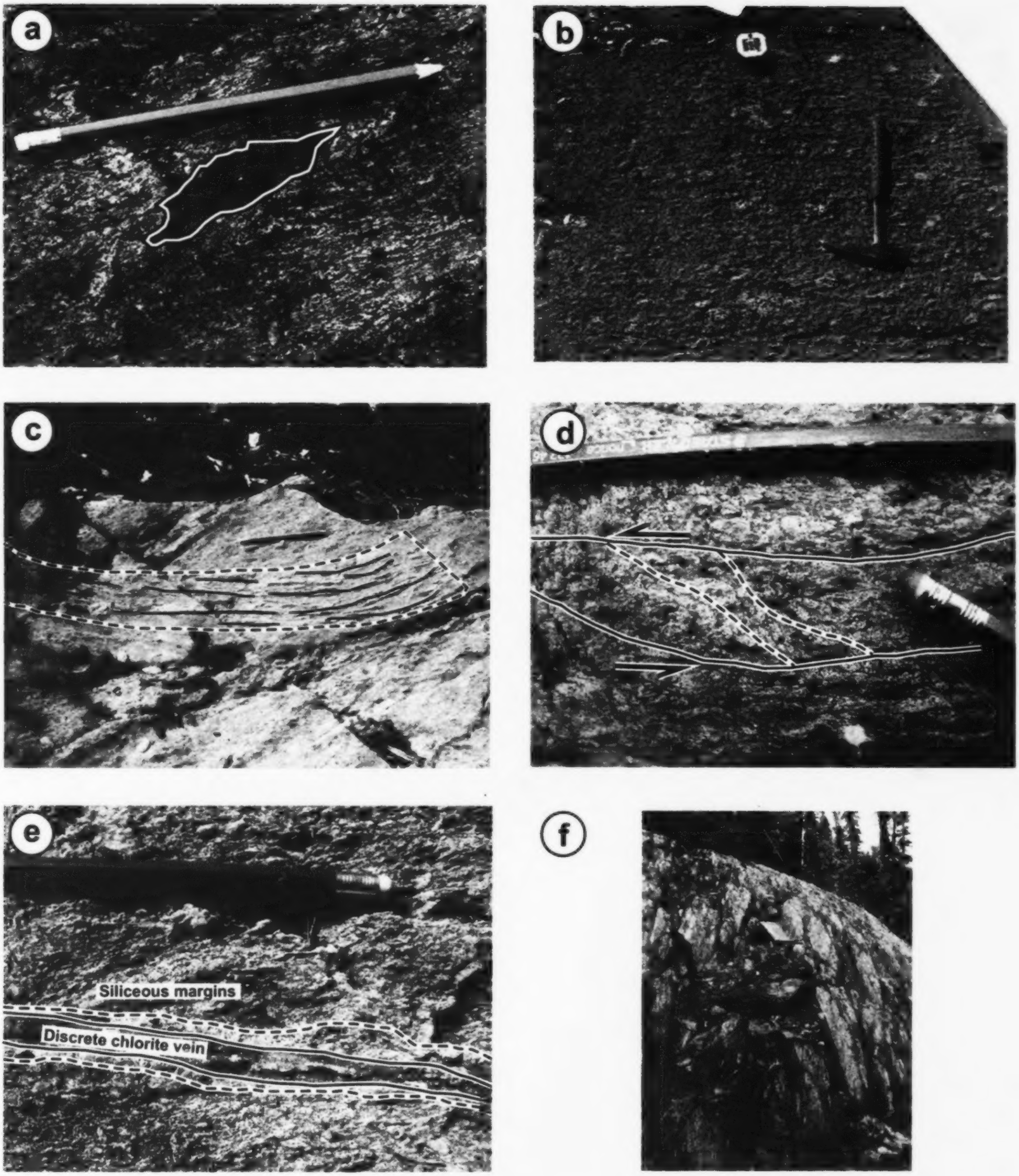

Figure GS-3-5: *Outcrop photographs of Schist Lake mine volcaniclastic lithofacies:* ***a)*** *typical mafic volcaniclastic facies, showing aphanitic, aphyric mafic clast (outlined) in a mottled, brown-white sericitic matrix;* ***b)*** *typical felsic volcaniclastic facies, containing white, angular felsic clasts in a mafic (?) matrix; unit is moderately sorted with respect to clast size;* ***c)*** *clast of plane-bedded tuff (outlined by dashed line, beds are solid lines) in a brown mafic matrix;* ***d)*** *C/S fabric in a sericite-altered felsic unit; the early foliation (dashed line) curves into the late foliation (solid line), indicating a sinistral sense of movement;* ***e)*** *chlorite vein (outlined by solid black lines) with more resistant, siliceous margins (outlined by dashed lines) in a sericite-altered felsic unit;* ***f)*** *irregular network of massive, green to black chlorite veins up to 20 cm wide in a more massive mafic unit (possible stringer zone); veins generally have an ~315° orientation.*

change in orientation as it passes into the plane of the main foliation. This geometry, together with an increase in fabric development in the shear zone, suggest that the second foliation is a mylonitic S-fabric that was displaced along the main foliation, which acted as a C-fabric during sinistral, east-side-up shear parallel to lineation (Figure GS-3-5d).

Alteration facies descriptions and mineralization

The Schist Lake mine peninsula exhibits four different types of alteration: 1) iron staining, 2) chlorite, 3) sericite, and 4) quartz veining (Figure GS-3-6).

Iron staining

Iron staining is a common occurrence in the rocks of the Schist Lake mine area, particularly in the eastern block, where it imparts a bright orange red to deep purple colour, when it is more intense, to the otherwise light-coloured rocks. The stained zones are parallel to the main foliation and are linear in appearance, with a tendency to follow shear zones or fractures. Along fractures, the hostrock is more intensely altered to a deep purple colour that diffuses outwards to red and then orange. These iron-stained zones are found throughout the area (Figure

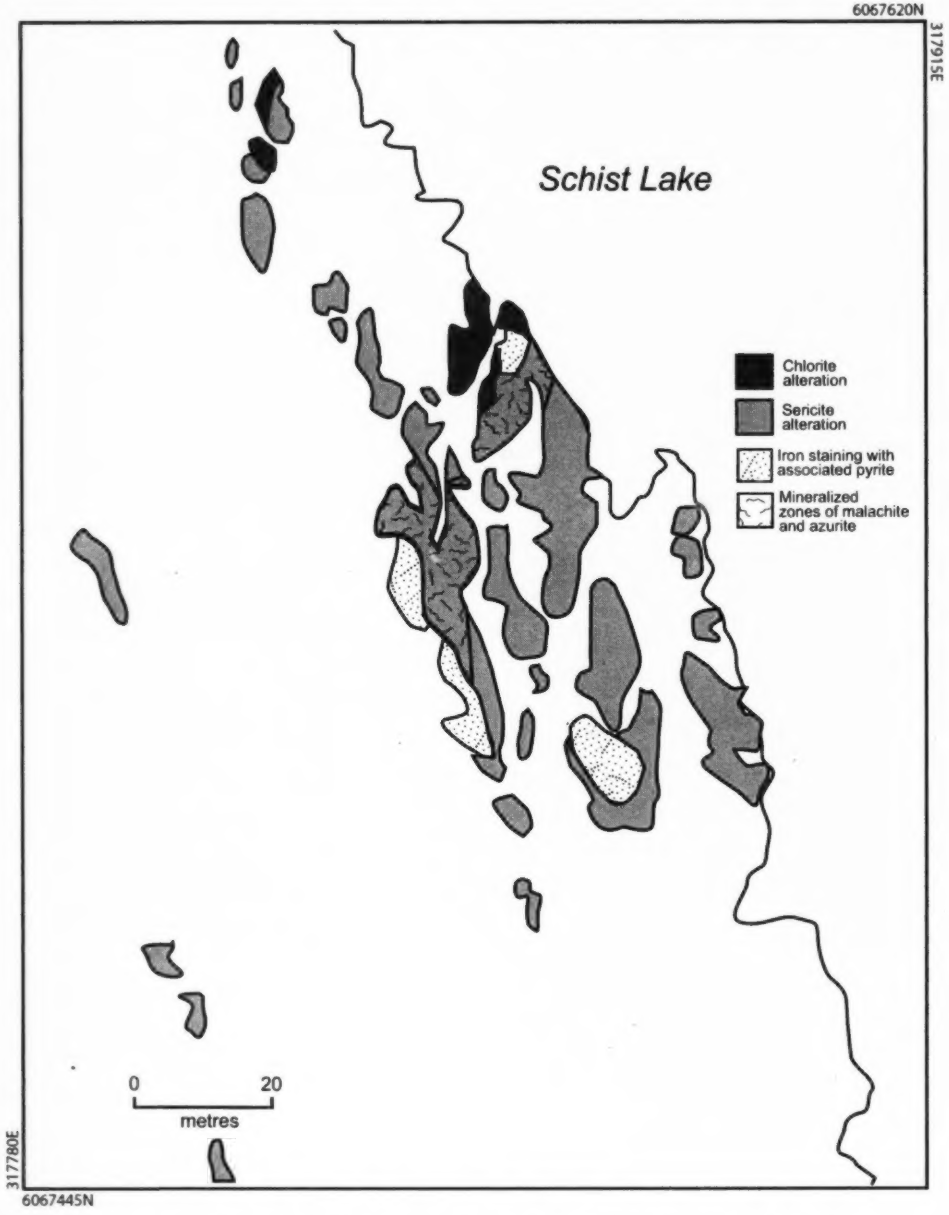
6067620N
317915E
Schist Lake
Chlorite alteration
Sericite alteration
Iron staining with associated pyrite
Mineralized zones of malachite and azurite
0
20
metres
317780E
6067445N

Figure GS-3-6: Outcrop alteration of part of the eastern shore of the Schist Lake mine peninsula.

GS-3-6) and also as spots scattered within the rock. The stained zones have diffuse boundaries with the hostrock.

Chlorite

Chlorite alteration is found in two morphologies: as a vein stockwork and as small discrete veins. Where the chlorite is found as veins, it is a dark green black colour. This alteration feature is particularly prominent on the western shore of Schist Lake (Figure GS-3-6), where it forms 5–25 cm wide stockwork veins that are orientated ~315° and almost vertical (Figure GS-3-5f). These veins cover an area of 20 m^2 and gradually decrease in size farther inland, where they almost disappear except for isolated patches. Isolated patches of chlorite veins occur throughout the strata of the mine peninsula.

The second type of chlorite alteration is found as discrete chlorite veins with resistant silicified envelopes (Figure GS-3-5e). This type of alteration is found proximal to the main chlorite alteration zone and the veins are randomly orientated.

Both types of chlorite alteration are surrounded by areas of iron-stained rock.

Sericite

Sericite alteration occurs throughout most of the lithofacies of the eastern block (Figure GS-3-6), where it imparts a whitish appearance and, when scraped, has a chalky nature (Figure GS-3-5a). It occurs along foliation planes and is most prominent in the more massive felsic units, producing rocks that are very white in colour. The contact between sericitized and nonsericitized areas is indistinct and gradational.

Quartz veining

Quartz veins are observed in most parts of the peninsula, particularly in the eastern block, where they have various thicknesses. The most common quartz veins are <1 cm thick and randomly oriented, and crosscut their hostrocks in a network pattern. Localized quartz veins, 1–3 m in thickness, are associated with areas of intense iron staining, whereas other quartz veins that range from 10–20 cm in thickness trend northeast but have a limited strike length.

Mineralization

Other than the Schist Lake mine, only small surface occurrences of mineralization have been found in the Schist Lake mine area, mostly within strata of the eastern block. Malachite has been observed within the plane of the main 340° foliation, along with chalcopyrite and azurite. Small patches of disseminated pyrite are also common, most notably within the iron-stained zones.

Interpretation

The Schist Lake mine peninsula consists mostly of coarse volcaniclastic rocks. The different clast types observed in the various volcaniclastic facies suggest multiple sources and mixing. The absence of proximal volcanic facies, such as flows, and the abundance of volcaniclastic rocks suggest a more distal depositional environment (Fisher and Schmincke, 1984). The angularity of clasts, well-sorted character and wide range of sizes (1–45 cm) all suggest that there has been a moderate amount of transportation of volcanic debris (Fisher and Schmincke, 1984), although this varies from unit to unit, given the variable sorting and clast shape. Most of the volcaniclastic units are clast supported, with fine-grained material making up the matrix. This suggests that the volcaniclastic facies were transported and deposited by high-concentration mass flows. The observed thickness of the volcaniclastic units is at least 200 m, which may include some structural thickening. The abundance and thickness of the volcaniclastic deposits suggests that they were deposited in a basin.

Alteration is more prominent east of the main shear, where chlorite and sericite alteration are more pervasive. Iron staining is preferentially developed along fractures and small shear zones. The chlorite vein alteration present in the eastern block is typical of that found in footwall VMS deposits (Grifkins et al., 2005), which suggests that the east block of the Schist Lake mine area may contain footwall strata of the Schist Lake deposit. The rocks in the west block show very little alteration, except for small localized patches of iron staining and sericite alteration. This would be consistent with alteration observed in the hangingwall to VMS deposits (Grifkins et al., 2005), although it has not yet been determined if the western block represents the hangingwall.

Economic considerations

Although the Schist Lake and Mandy deposits were the first to be mined in the Flin Flon area, their stratigraphy and relationship to the other Flin Flon VMS deposits is still not known. The stockwork chlorite veins and sericite alteration within the east block suggest that this block contains the footwall strata to the Schist Lake deposit. The main shear zone may have dismembered the Schist Lake orebody along the main foliation and lineation plunge, and the sinistral and vertical offset on this shear suggests that hangingwall strata to the Schist Lake deposit may occur farther to the south and deeper.

Acknowledgments

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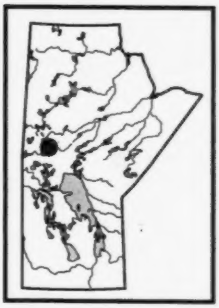
GS-4 Investigation of a Pb-Ag-Au–rich hangingwall in lens 4 of the Chisel North mine, Snow Lake, Manitoba (NTS 63K16): preliminary results

by S. Gagné[1], C.J. Beaumont-Smith, A.E. Williams-Jones[1]
and A. Hynes[1]



Gagné, S., Beaumont-Smith, C.J., Williams-Jones, A.E. and Hynes, A. 2007: Investigation of a Pb-Ag-Au–rich hangingwall in lens 4 of the Chisel North mine, Snow Lake, Manitoba (NTS 63K16): preliminary results; *in* Report of Activities 2007, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 43–50.

Summary

Preliminary petrographic and electron microprobe study of mineralized samples collected from the Pb-Ag-Au–enriched hangingwall of lens 4 in the Chisel North mine was undertaken in order to characterize the setting of the mineralization, study the effect of metamorphism and evaluate possible structural controls. The hostrock is a medium-grained garnet-bearing amphibolite with disseminated arsenopyrite and galena-rich veinlets. The petrographic examination indicates that there is likely no paragenetic relationship between arsenopyrite and gold. Galena veinlets are characterized by complex intergrowth and replacement textures between galena and various sulphosalts. The sulphosalts are the main Ag-bearing phase and native Au is commonly found as inclusions or in contact with Ag-rich sulphosalts. The observation of common minute inclusions of native gold along late, galena-rich veins is indicative of a late emplacement of the Au mineralization; however, rare inclusions of sulphide and Au in garnet or amphibole porphyroblasts suggest that the hangingwall was enriched in Pb-Ag-Au prior to attainment of peak metamorphic conditions. Although most of the Au mineralization occurs in association with late sulphide veinlets, the presence Au-sulphide inclusions in porphyroblasts suggests that the actual mineralization is the result of remobilization of an earlier Au generation.

Introduction

This report presents preliminary results of a project supported by the Manitoba Geological Survey (MGS) and the Geological Survey of Canada that aims to investigate the effects of metamorphism on Pb-Ag-Au hangingwall mineralization at the Chisel North mine (Figure GS-4-1) and to establish the relative timing of mineralization. It is part of a larger-scope regional Au metallogenic study of the Snow Lake greenstone belt. The 2007 field season was focused on completing the sample collection for the project. Within the scope of the associated Ph.D. research, other examples of Au and sulphide mineralization (Squall Lake, Puffy Lake and Nokomis Lake; Figure GS-4-1) will also be investigated. This contribution, however, focuses on the progress from the petrographic and electron microprobe study of samples from the Chisel North deposit.

Regional geology

The Chisel North mine is located about 12 km south of the community of Snow Lake. The deposit was discovered in 1987 during deep exploratory drilling 1.5 km north of the original Chisel Lake deposit. The Chisel North sulphide orebody is located at the same stratigraphic level as the main Chisel mine orebody, but 300 m down plunge. The nearby Ghost Lake and Lost Lake deposits also occur along the same stratigraphic horizon. The Chisel North orebody is a stratabound, proximal, volcanic-hosted massive sulphide (VMS) deposit (Galley et al., 1993) in which sulphide mineralization occurs mainly as silicate-dolomite–rich semimassive to massive sphalerite-pyrite lenses (Bailes and Galley, 1996).

The Chisel North deposit is hosted by evolved subaqueous volcanic rocks from the mature portion of the 1.8–1.9 Ga Snow Lake arc assemblage (Bailes and Galley, 1996, 1999). The Amisk Group volcanic and volcaniclastic rocks of the Snow Lake assemblage have been divided into five depositional phases by Galley et al. (1993). The first phase is dominated by mafic volcanism and includes basalt and basaltic andesite. The second phase starts with the deposition of felsic breccia followed by rhyolite and basalt extrusion, and terminates with the deposition of mafic wacke and breccia. The third phase consists of aphyric basalt and breccia at the base, overlain by the Powderhouse feldspar-phyric dacite and the Chisel and Ghost Lake rhyolite units at the end of the cycle. The fourth depositional phase comprises mafic basalt, wacke and breccia, topped by felsic volcanic rocks. The Chisel North deposit occurs at the contact between felsic volcanic and associated volcaniclastic rocks of the third depositional phase and mafic volcanic and reworked volcaniclastic rocks of the fourth phase (Galley et al., 1993). The last depositional cycle consists mostly of pillowed aphyric basalt.

The Chisel Lake and Chisel North deposits are located within a northwest-trending, pre-D_3, synformal fold interference structure locally known as the Chisel basin. The Chisel basin is an ~5 km thick arc assemblage comprising mainly mafic wacke, mafic breccia, pillowed basalt, synvolcanic gabbro intrusions and felsic volcanic components, including the Powderhouse feldspar-phyric

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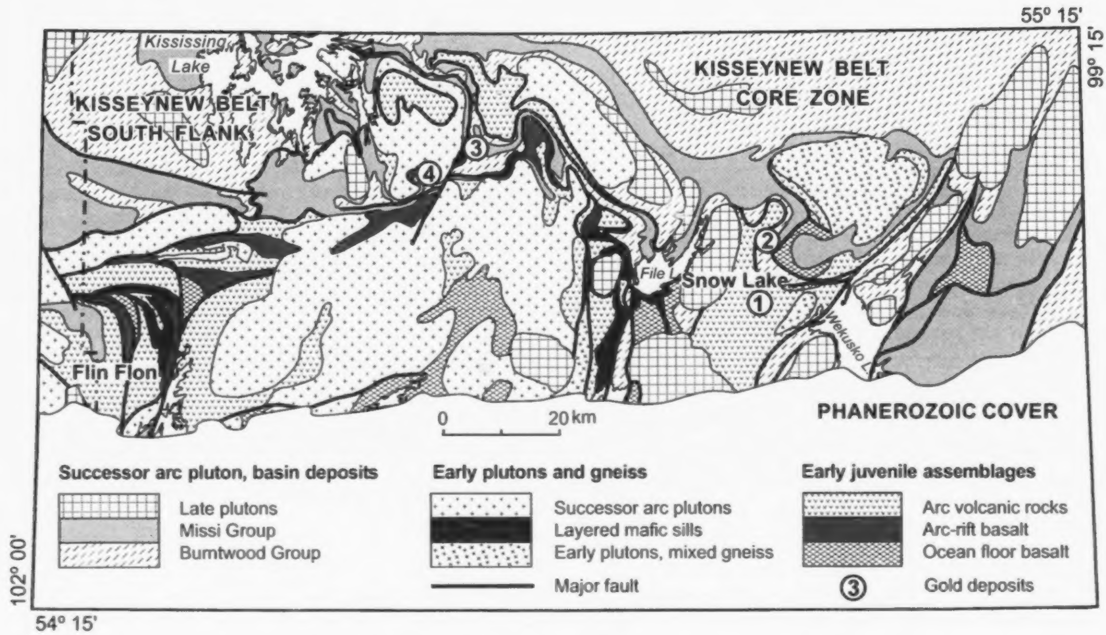

55° 15'
99° 15'
Kississing Lake
KISSEYNEW BELT SOUTH FLANK
KISSEYNEW BELT CORE ZONE
File L
Snow Lake
Wekusko L
Flin Flon
①
②
③
④
0
20 km
PHANEROZOIC COVER
Successor arc pluton, basin deposits
Late plutons
Missi Group
Burntwood Group
Early plutons and gneiss
Successor arc plutons
Layered mafic sills
Early plutons, mixed gneiss
Major fault
Early juvenile assemblages
Arc volcanic rocks
Arc-rift basalt
Ocean floor basalt
③
Gold deposits
102° 00'
54° 15'

Figure GS-4-1: *Regional geology of the Flin Flon–Snow Lake greenstone belt.*

dacite and the quartz-feldspar–phyric Chisel rhyolite and associated volcaniclastic rocks.

Four generations of folds have been identified in the Snow Lake area (Kraus and Williams, 1999), with the three earliest phases having the most effect on the ore geometry at Chisel North. The first deformational event developed isoclinal folds that trend northwest and were accompanied by regional low-grade (greenschist-facies) metamorphism. The second deformational phase also generated isoclinal folds, but these folds have a northeast trend and were accompanied by peak pressure-temperature (P-T) conditions of the lower-amphibolite facies in the Chisel area (Bailes et al., 1996). The regional structural geometry is dominated by open northwest-trending folds produced during the third deformational event. The F_3 Threehouse synform folds the thrust-imbricated Burntwood Group turbidites and Amisk Group volcanic rocks in the Snow Lake area about a shallow- to moderate-plunging axis that also corresponds to the regional stretching lineation (Kraus and Williams, 1999). Menard and Gordon (1995) carried out thermobarometric calculations for the Photo Lake mine and calculated peak P-T conditions of approximately 5 kbar and nearly 535°C.

Previous work

The prolific Snow Lake mining camp, which is host to more than 15 VMS deposits, has been the subject of many studies spanning a broad range of topics over the last two decades. Froese and Moore (1980) provided the first sound understanding of the metamorphism in the vicinity of Snow Lake. The area around Chisel North was mapped at a regional scale by the MGS (Bailes et al., 1996). Galley et al. (1993) and Bailes and Galley (1996, 1999) examined in detail the alteration and mineralization of the Chisel and Chisel North orebodies. Zaleski et al. (1991) investigated the metamorphosed alteration at the Linda deposit, which records peak P-T conditions similar to those in the Chisel Lake area. Their work focused on the mineral equilibrium of altered metamorphosed wallrock that has been enriched in Zn and F. Menard and Gordon (1995) studied the effect of metamorphism on sulphide ore and metamorphosed wallrock at the Photo Lake deposit and found evidence for local synmetamorphic alteration of the orebody wallrocks. For example, they recognized that within 5 m of the deposit, the cores of garnets contained sulphides in much greater abundance than the rim or surrounding matrix, suggesting the removal of sulphides during garnet growth. This is likely the result of variations in fO_2 and fS_2 conditions driven by the metamorphic fluid, which may have resulted in the formation of a sulphidization and oxidation halo around the orebody. Recognition of a sulphidization-oxidation halo around an orebody is important, since it means that the variation of fO_2 and fS_2 conditions was significant. It also implies that altered wallrock within the sulphidization-oxidation halo does not simply represent the result of isochemical metamorphism of the original synvolcanic alteration. Menard and Gordon (1995) also identified various settings of Au, including along late fractures filled with serpentine, which was interpreted as the result of remobilization during the third deformational event.

Objectives of the study

The objectives for the Chisel North study are to establish the origin and relative timing of the hangingwall Pb-Ag-Au mineralization, study the effect of lower-amphibolite–facies metamorphism on ore mineralogy, investigate metamorphic sulphide-silicate-oxide interaction, verify for the presence of a metamorphic sulphidization-oxidation halo around the deposit and, if confirmed, investigate the effect of the halo on host mineralogy and mineral composition. Also, particular attention will be paid to the processes involved in the remobilization of Pb-Ag-Au.

Deposit geology

The Chisel North deposit comprises a series of shallowly northeast-dipping massive sulphide lenses (Figure GS-4-2). The lenses are located along the same stratigraphic horizon as the adjacent Chisel Lake deposit, and the Chisel North deposit appears to be a down-plunge extension of the Chisel Lake deposit (Galley et al., 1993). The stratabound deposit is composed of four stacked lenses, whose long axes plunge subparallel to the regional stretching lineation and the axis of the Threehouse synform. The lenses are stacked in an en échelon fashion down the dip of the stratigraphy. The relationship between the ore lenses is not well understood.

The Chisel North ore typically consists of up to 20 m of silicate-dolomite–rich, semi-massive sphalerite-rich ore with thin, massive sphalerite-pyrite or sphalerite bands containing up to 100% sulphide minerals. Pyrite is typically more abundant near the base of the ore horizon and locally massive pyrrhotite occurs near the hangingwall. The ore horizon is locally underlain by discordant zones of disseminated and vein sulphides, comprising mostly chalcopyrite and pyrrhotite. Throughout the deposit, the hangingwall is locally variably enriched in Au, Ag and Pb with values reaching as much as 7–10 g/t Au, 300 g/t Ag and 1% Pb over a few metres. The hangingwall mineralization, however, is heterogeneously distributed and is typically found associated with tectonically remobilized sulphide veins. In the hangingwall of lens 4, where samples were collected, mineralization is associated with both late sulphide veins and disseminated arsenopyrite in the altered wallrock.

The hangingwall to the mineralization consists of mafic volcanic wacke in the southern third of the Chisel North deposit, whereas the rest of the orebody is overlain by a heterolithic breccia, locally truncated by a fine-grained dioritic intrusion (Galley et al., 1993). In the vicinity of lens 4, the hangingwall is mostly occupied by the dioritic sill. The footwall to the Chisel North sulphide lenses is generally the quartz-feldspar–phyric Chisel rhyolite and its volcaniclastic equivalents that have been recrystallized and hydrothermally altered to currently consist of sericite and chlorite with common kyanite, biotite, staurolite and garnet porphyroblasts (Galley et al., 1993). Within the immediate vicinity of the area sampled in fall 2006, the intensity of alteration and metamorphic recrystallization renders the hangingwall rock difficult to identify with confidence.

Current mining activities afforded the opportunity to conduct complete reconnaissance structural analysis in two areas of the sulphide lens 2 of the Chisel North mine, which sits structurally above lens 4. One area is an undercut that exposes the immediate footwall-altered Powderhouse dacite (2 Zone, 5 South lower) and the second area is a series of drifts through the ore zone (2 Zone, 8–11 South upper). In the areas visited, the orebody appears highly deformed. Both the mineralization and hostrocks are well foliated and isoclinal folds are pervasive. Sulphide mineralization exhibits penetrative deformation structures and local redistribution of constituent mineral phases; accordingly, Tessier (2001a, b) speculated that there is a strong likelihood that the distribution of the mineralization is most probably fold controlled. The orientation of D_1 and D_2 structures observed in this project supports this assertion, but further structural analysis is required to adequately demonstrate fold control.

Fabric elements and overprinting relationships developed in the orebody are the products of four discrete periods of ductile deformation, consistent with the regional structural history of the Snow Lake area established by Kraus and Williams (1999). Deformation structures in the mine are dominated by shallowly inclined to recumbent, subhorizontally plunging F_2 folds and pronounced L_2 crenulation lineation (Figure GS-4-3a, b). This generation of structures corresponds to the D_1 deformation of Martin (1966) in the adjacent Chisel Lake mine. These folds plunge northwest and refold isoclinal intrafolial F_1 folds (Figure GS-4-4a). The F_1 folds are recumbent and appear to plunge shallowly west. The two generations of tight to isoclinal folds (F_1 and F_2) produce a complex mesoscopic fold interference pattern (Figure GS-4-4b). Primary layering is locally preserved (Figure GS-4-5) and outlines F_1 folds, but rocks in the mine generally have structural fabrics consistent with transposition of the orebody and hostrocks and a composite S_1-S_2 transposition foliation is ubiquitous. In the siliceous footwall to the mineralization (2 Zone, 5 South lower), the transposition foliation is manifested as a differentiated layering defined by alternating sericitic bands and transposed sulphide (dominantly pyrite) stringers (Figure GS-4-5). The existence of the earlier F_1 generation of folds was not fully appreciated during the underground structural analysis at the adjacent and genetically related Chisel Lake deposit, although Martin (1966) postulated the possibility of an older generation of isoclinal folds, based on the statistical analysis of structural orientation data.

Overprinting the F_1-F_2 geometry are two generations of crossfolds (F_3 and F_4). The F_3 folds are upright, open

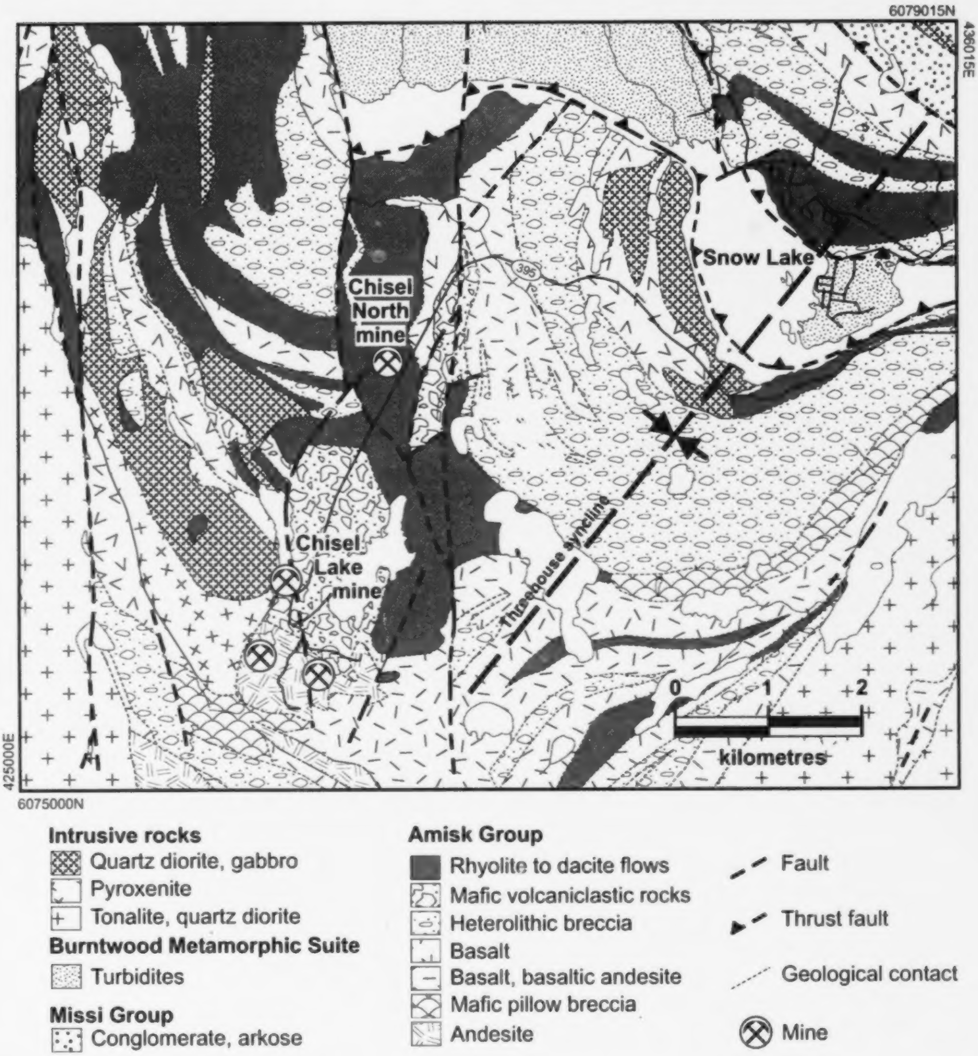

6079015N
436015E
Snow Lake
395
Chisel North mine
Chisel Lake mine
Threehouse syncline
0
1
2
kilometres
425000E
6075000N
Intrusive rocks
Quartz diorite, gabbro
Pyroxenite
Tonalite, quartz diorite
Burntwood Metamorphic Suite
Turbidites
Missi Group
Conglomerate, arkose
Amisk Group
Rhyolite to dacite flows
Mafic volcaniclastic rocks
Heterolithic breccia
Basalt
Basalt, basaltic andesite
Mafic pillow breccia
Andesite
Fault
Thrust fault
Geological contact
Mine

Figure GS-4-2: *General geology of the Snow Lake area.*

to close folds (Figure GS-4-6a) and are associated with a weakly developed axial planar foliation and locally pronounced crenulation lineation (Figure GS-4-6b). The F_3 crossfolds are associated with the regional northeast-trending Threehouse synform and the orientation of the L_3 lineation is parallel to the regional stretching lineation (*see* Kraus and Williams, 1999). The F_3 crossfolds may be responsible for the large open warps apparent in the mineralization and may be an important control on high-grade, remobilized mineralization (Tessier, 2001a, b). Moderately to shallowly plunging, open to box F_4 folds are locally observed. These folds do not appear to represent a significant feature with respect to reorienting the mineralization.

Folding has had a pronounced effect on the distribution of the mineralization in the areas of the mine that were visited. This is consistent with the distribution of mineralization at the Chisel Lake mine (Martin, 1966). The intensity of the early folding events produced significant fold thickening of mineralization observed mesoscopically; therefore, by analogy, there is a high likelihood that the orebody has experienced significant fold thickening during the early periods of deformation. Layer-parallel attenuation and boudinage of high-grade, sphalerite-rich mineralization is also common.

The relationship between the ore lenses is not well understood. The orientation and the distribution of the ore lenses suggest that the geometric relationship between the lenses may be a product of F_2 folding. The four ore zones form a series of stacked, stratigraphically upward- facing lenses (Tessier, 2000, 2001a, b). Based on a review of Tessier (2000, 2001a, b) and the limited structural analysis undertaken in this study, the structural geometry for this arrangement can be explained by the

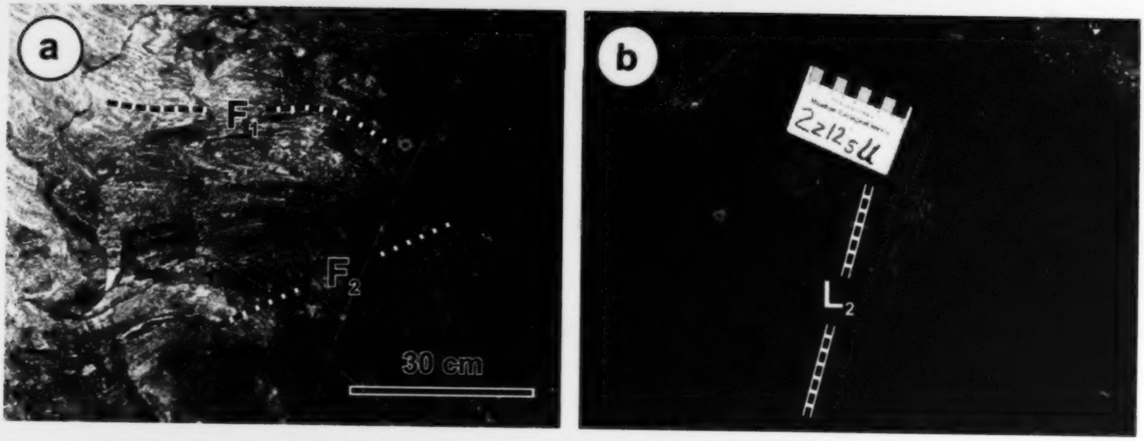

a
F_1
F_2
30 cm
b
2212sU
L_2

Figure GS-4-3: *Elements of D_2 fabric:* ***a)*** *recumbent F_2 fold refolding F_1 isoclinal folds;* ***b)*** *L_2 crenulation lineation developed in sericitized Powderhouse dacite.*

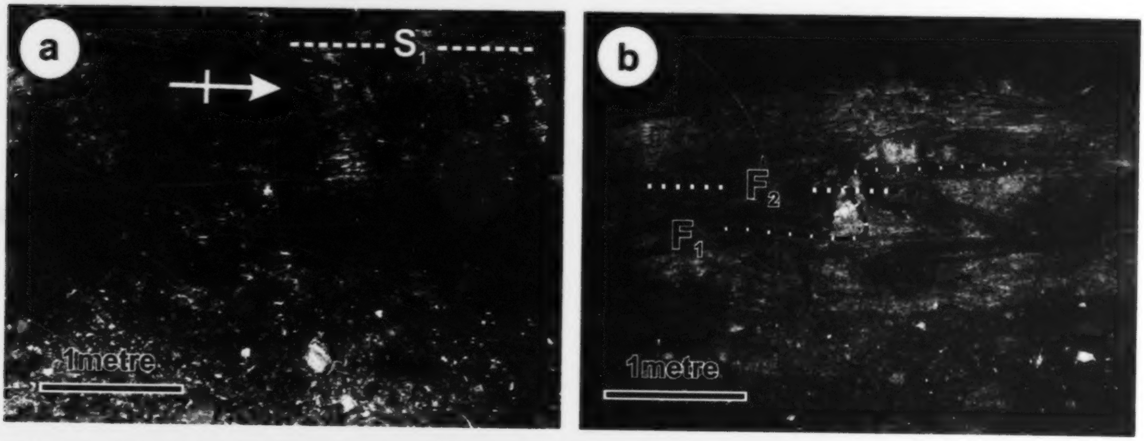

a
S_1
1metre
b
F_2
F_1
1metre

Figure GS-4-4: *Elements of D_1 fabric:* ***a)*** *F_1 isoclinal folds;* ***b)*** *F_1-F_2 fold interference pattern.*

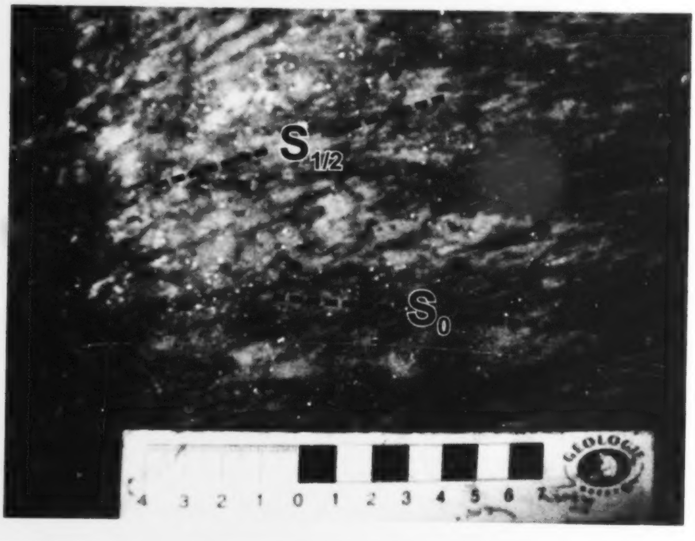
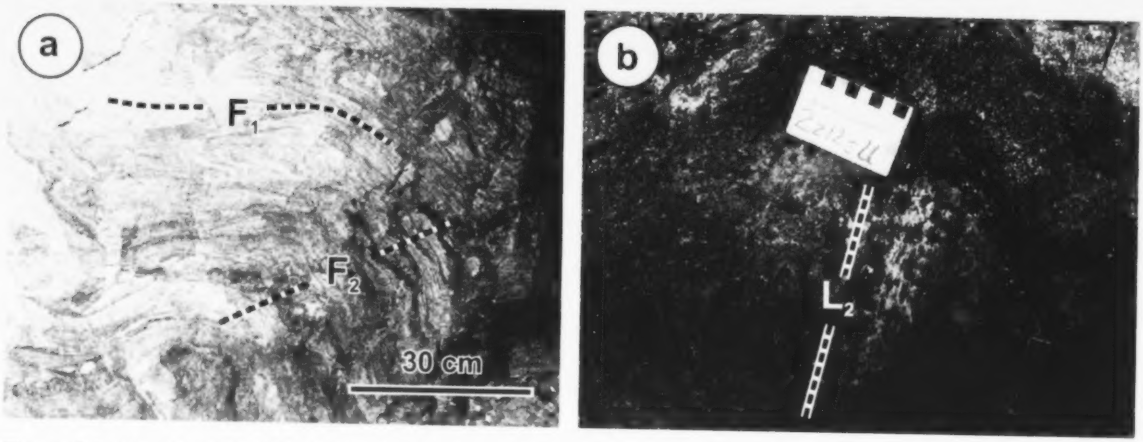

$S_{1/2}$
S_0
4 3 2 1 0 1 2 3 4 5 6 7

Figure GS-4-5: *Transposition foliation, S_1-S_2, developed in the footwall Powderhouse dacite.*


a
F1
F2
30 cm
b
L2

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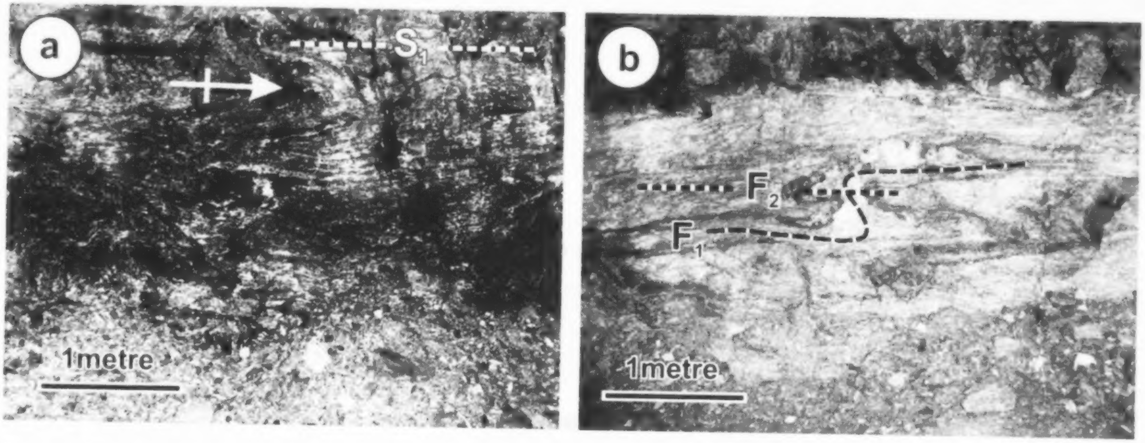
a
S1
1metre
b
F2
F1
1metre

Figure GS-4-4: *Elements of D_1 fabric:* ***a)*** *F_1 isoclinal folds;* ***b)*** *F_1-F_2 fold interference pattern.*

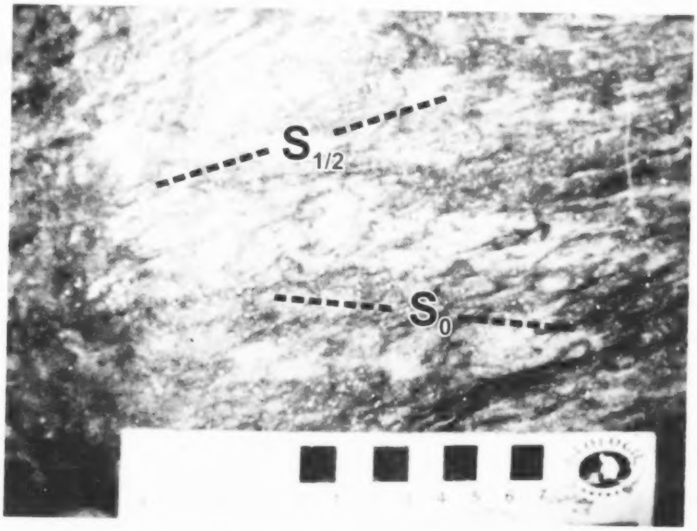

Figure GS-4-5: *Transposition foliation, S_1-S_2 developed in the footwall Powderhouse dacite.*

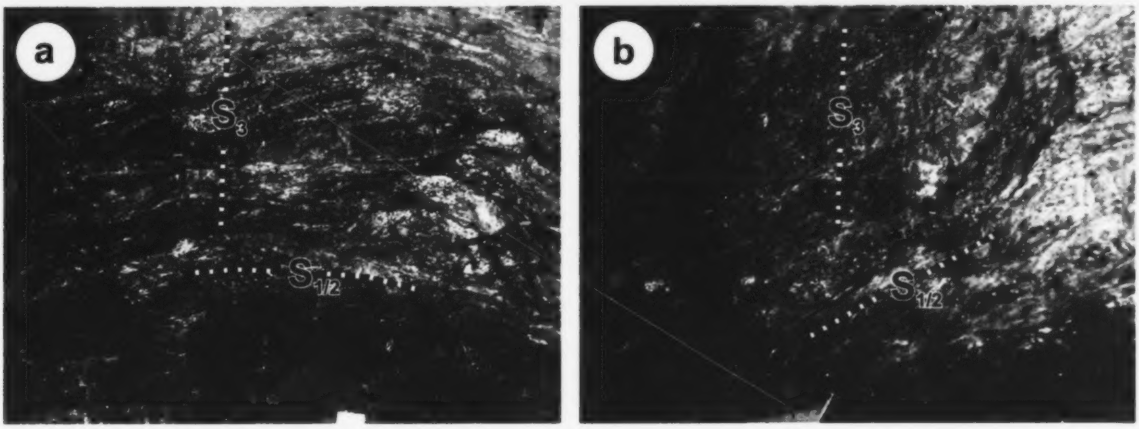

Figure GS-4-6: a) Open F$_3$ fold; b) associated weak crenulation cleavage.

development of highly attenuated, asymmetrical F$_2$ folds having consistently attenuated short-fold limbs maintaining the upward-facing direction. Although, note that the same geometry could also be explained by thrust faulting or episodic deposition along a primary synvolcanic fault. Additional structural analysis is required to determine the structural relationship between the ore lenses.

Hangingwall Pb-Ag-Au mineralization

Samples from the Pb-Ag-Au mineralization that occurs in parts of the hangingwall of lens 4 at the Chisel North mine were collected during the summer of 2006. Preliminary petrographic description and electron microprobe analysis work were completed on the sample suite. The hostrock to the mineralization is a moderately foliated, medium- to coarse-grained amphibolite with variable amounts of garnet and sulphide. The amount of garnet in the rock varies from 1 to 15%. Higher garnet content coincides with a greater abundance of disseminated arsenopyrite. Garnet varies from small (1–6 mm) euhedral crystals with 5–15% inclusions to large poikiloblastic masses (5–20 mm) with 20–50% inclusions. Actinolite also forms large (1–10 mm) poikiloblastic masses and is locally altered to chlorite.

Mineralized hangingwall typically contains garnet, arsenopyrite, galena and pyrrhotite with the highest Au-Ag values correlating with greatest galena content. Arsenopyrite is typically euhedral (1–5 mm). Although arsenopyrite is common in the mineralized hangingwall, it was not observed to contain any inclusions of Au, nor was it seen in direct contact with Au grains. Galena is mostly found infilling late fractures, but is also commonly observed as irregular masses within the matrix. Petrographic work and electron microprobe analysis have shown that most of what has been identified macroscopically as galena is in fact a complicated graphic and/or myrmekitic intergrowth between galena and various sulphosalts (Figure GS-4-7a, b), including

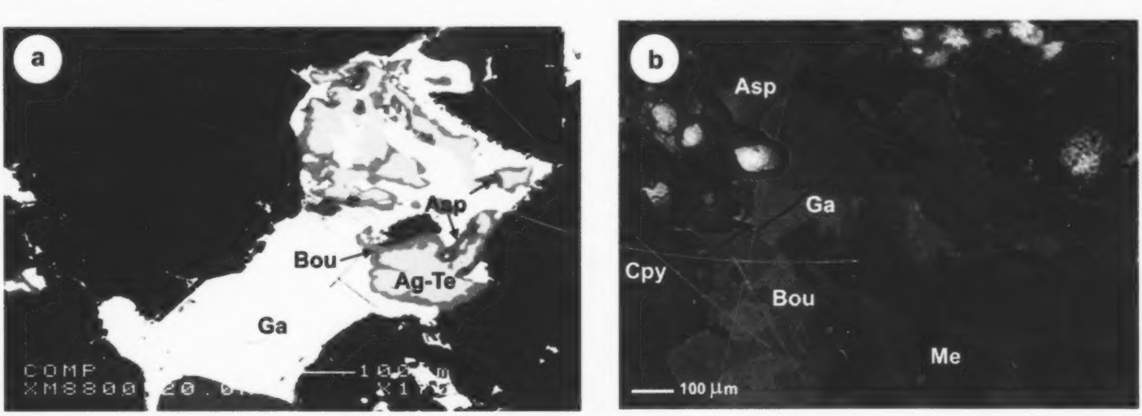

Figure GS-4-7: a) Electron-microprobe image of intergrowth of sulphosalts in galena, a complex zoning with core of Ag-rich tennantite surrounded by boulangerite, then galena; small graphic inclusions of arsenopyrite are present (field of view is 650 µm); b) optical microscope picture with inclusions of galena in boulangerite and complex meneghinite intergrowths (field of view is 600 µm); mineral abbreviations: Ag-Te, Ag-rich tennantite; Asp, arsenopyrite; Bou, boulangerite; Cpy, chalcopyrite; Ga, galena; Me, meneghinite.

meneghinite ($Pb_{13}CuSb_7S_{24}$), boulangerite ($Pb_5Sb_4S_{11}$), jordanite ($Pb_{14}(As,Sb)_6S_{23}$) and Ag-rich tennantite ($(Ag,Cu,Fe)_{12}(Sb,As)_4S_{13}$). Silver is mostly hosted in the structure of Ag-rich tennantite. Preliminary electron-microprobe analyses have yielded Ag content varying from 22 to 28 wt% for Ag-rich tennantite. Galena and other sulphosalts typically have low Ag content (less than 1000 ppm).

The common occurrence of galena and associated sulphosalts along late fractures, and the fact that they commonly rim other sulphide phases, such as arsenopyrite, chalcopyrite, pyrite and pyrrhotite, suggest that the former minerals crystallized later than other sulphides (Figure GS-4-7a).

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In summary, galena and sulphosalts appear to have been recrystallized and remobilized late in the

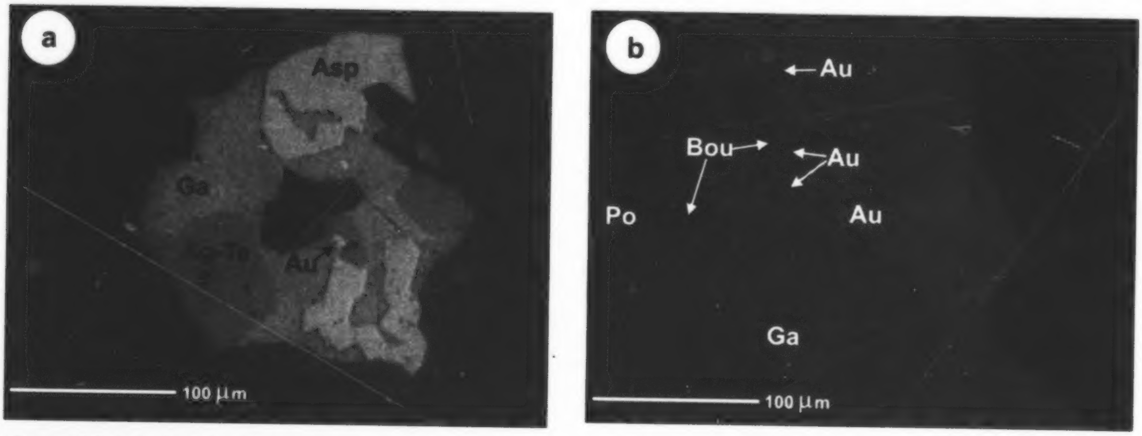


Figure GS-4-8: *Gold in association with sulphide mineral phases:* ***a)*** *sulphide inclusion in garnet porphyroblast showing a small Au inclusion in Ag-rich tennanite, which is intergrown with galena (field of view is 1200 µm);* ***b)*** *gold inclusions in galena and along the grain boundary between galena and boulangerite (field of view is 240 µm); mineral abbreviations: Ag-Te, Ag-rich tennantite; Asp, arsenopyrite; Au, gold; Bou, boulangerite; Ga, galena; Grt, garnet; Po, pyrrhotite.*

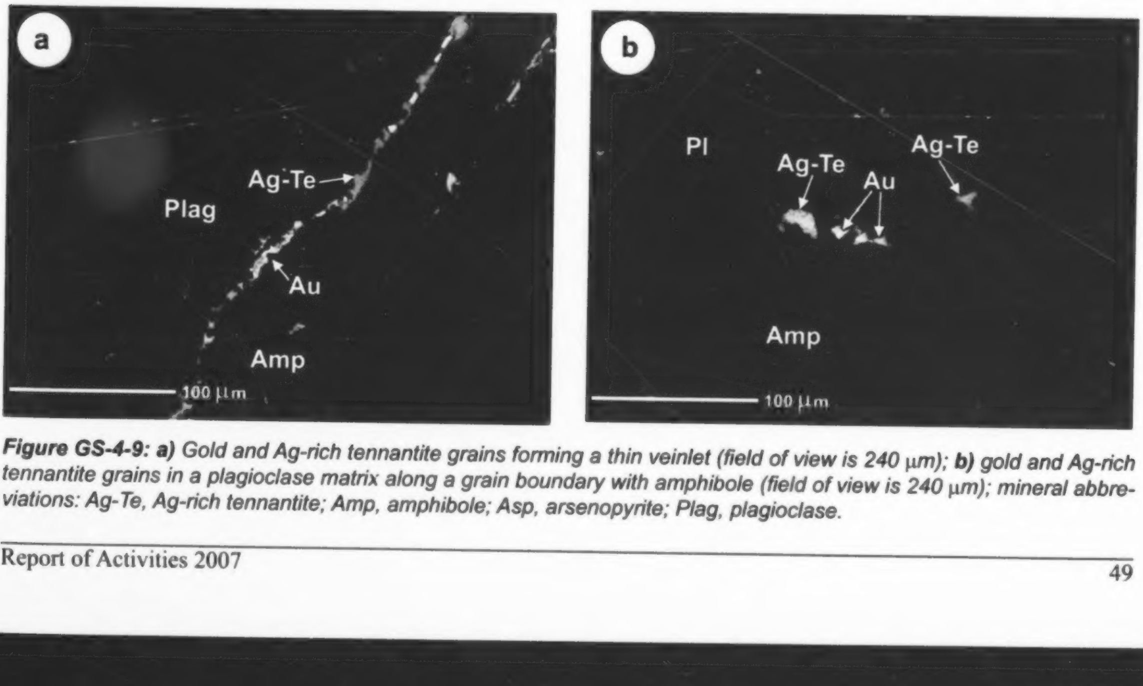
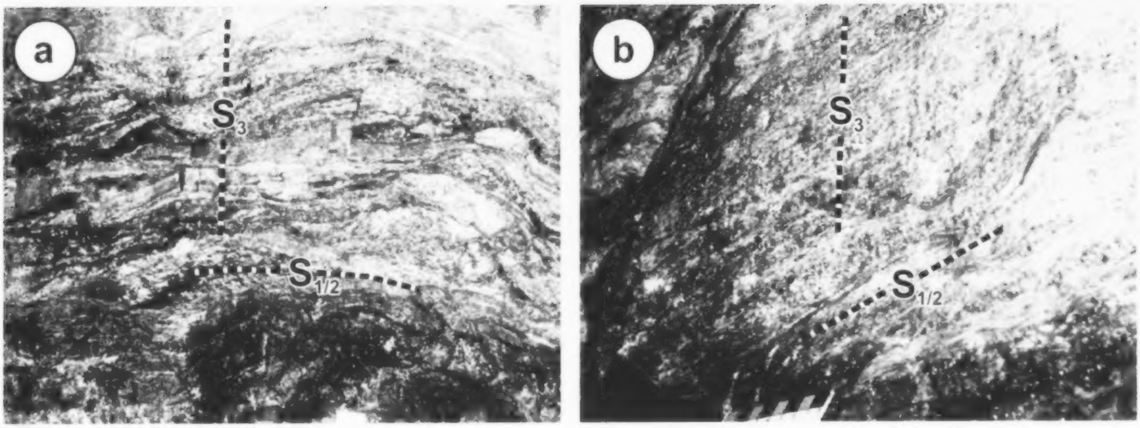


Figure GS-4-9: ***a)*** *Gold and Ag-rich tennantite grains forming a thin veinlet (field of view is 240 µm);* ***b)*** *gold and Ag-rich tennantite grains in a plagioclase matrix along a grain boundary with amphibole (field of view is 240 µm); mineral abbreviations: Ag-Te, Ag-rich tennantite; Amp, amphibole; Asp, arsenopyrite; Plag, plagioclase.*



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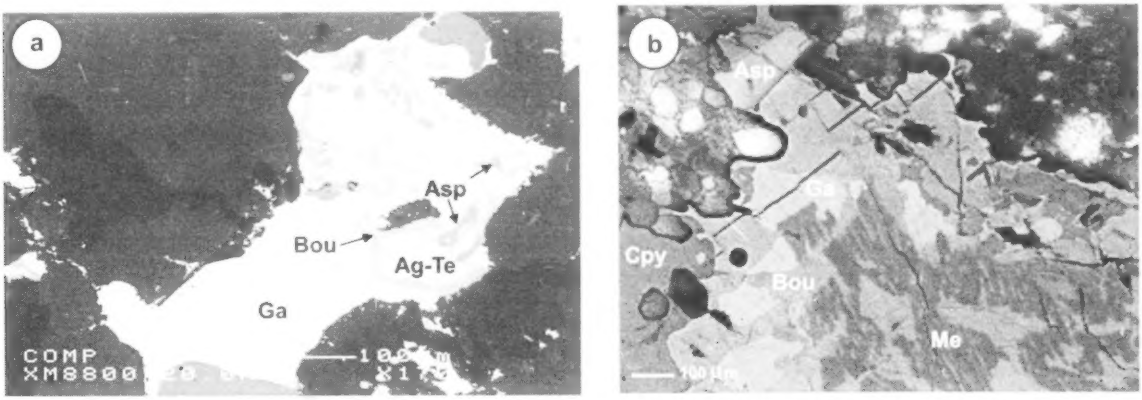

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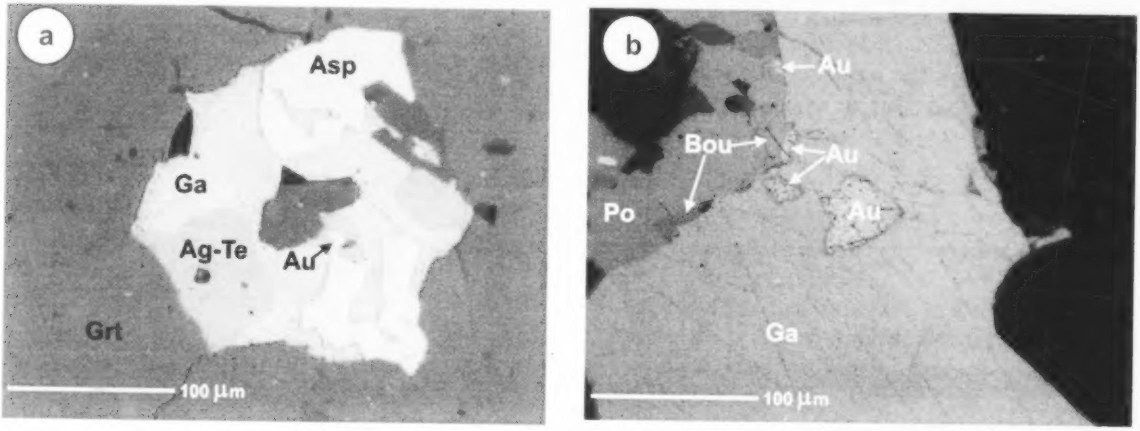

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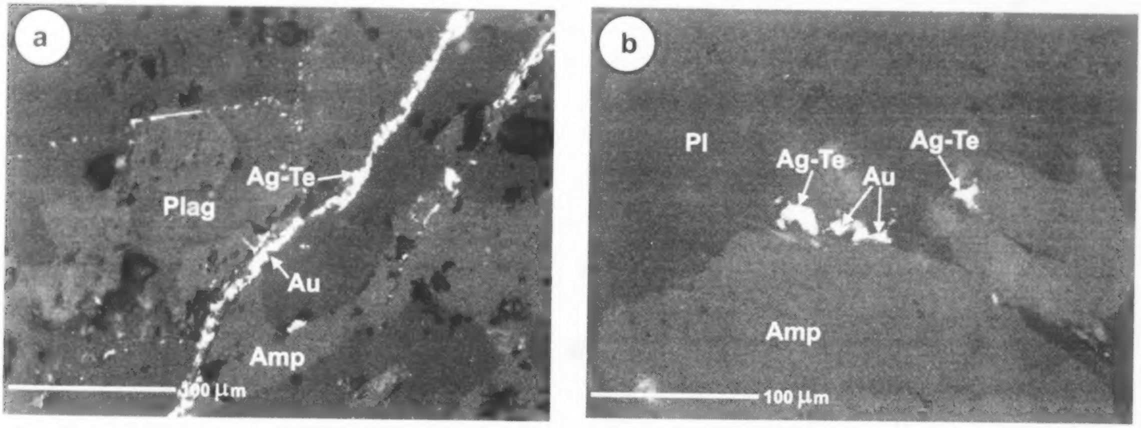

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paragenesis. Gold is mostly associated with galena and Ag-rich tennantite. Several occurrences of Au and sulphosalts along fractures suggest a late structural emplacement or remobilization, whereas a few occurrences of Au and sulphosalts included in porphyroblast indicates that the hangingwall was already enriched in Pb-Ag-Au prior to peak metamorphism. These textural relationships, however, do not permit the unequivocal statement of whether the hangingwall mineralization was synvolcanic (i.e., related to the VMS mineralization), had resulted from late remobilization of Pb-Ag-Au from main orebody or had resulted from *in situ* remobilization of a postvolcanic Pb-Ag-Au mineralization event.

Future work would require collecting oriented samples to verify the structural controls on the mineralization and more petrographic work to establish with confidence the paragenetic sequence and the timing of remobilization.

Economic considerations

Investigation of sulphide-Au mineralization will provide new constraints on the timing of mineralization and a better understanding of the mineralogical and compositional consequences of mid-amphibolite–facies metamorphism on sulphide-dominated ore. The study will also increase knowledge of sulphide-silicate-oxide interaction during prograde metamorphism and help understand the effect of sulphidization and oxidation halo on altered wallrock. This information may provide useful guidelines to help explorationists in the selection of exploration targets in medium- to high-grade metamorphic terranes.

Acknowledgments

Funding for this field season was generously provided by the Manitoba Geological Survey, the Geological Survey of Canada and McGill University. The authors also wish to acknowledge the support of Hudson Bay Mining and Smelting Co. Ltd. for allowing access to the Chisel North underground mine, for providing access to the drillcore samples, and for the valuable discussions with the mine staff. S. Gagné would especially like to thank E. Fluskey and S. Snyder, mine geologists at Chisel North, for taking time to guide him underground and explain the deposit. The authors also thank C. Currie for her invaluable field assistance.

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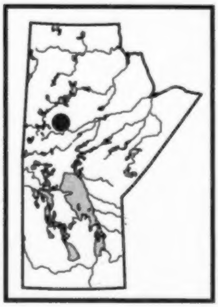
GS-5 Preliminary stratigraphy and structure of the Notigi Lake area, Manitoba (parts of NTS 63O14, 64B3)

by L.A. Murphy and H.V. Zwanzig

Murphy, L.A and Zwanzig, H.V. 2007: Preliminary stratigraphy and structure of the Notigi Lake area, Manitoba (parts of NTS 63O14, 64B3); *in* Report of Activities 2007, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 51–62.



Summary

The Notigi Lake area is an example of the stratigraphic and structural geology typical of the north flank of the Kisseynew Domain. It includes clean exposures of the Paleoproterozoic Burntwood and Sickle groups, as well as an amphibolite unit that is herein reinterpreted as metavolcanic and marking a regional crustal suture proposed by White et al. (2000). The updating of previous geological investigations, which involves subdividing the Sickle Group and taking new structural measurements, provides new details of the structural geometry and tectonic history of this important area. Interpretation of the field data compiled during the summer of 2007 delineates four stratigraphic units in the Sickle Group at Notigi Lake. This is based on the presence of certain metamorphic minerals that denote the compositions of arkose- and lithic arenite–derived gneiss. The structure is tentatively interpreted as a small refolded nappe, which may serve as a model for the crustal-scale structure that appears to feature recumbent isoclinal folding and upright refolding. With further work, this model may help to determine the three-dimensional distribution of 1) the amphibolite, which is gold bearing elsewhere; 2) newly discovered iron formation in the Burntwood Group; 3) traces of copper (malachite staining) in the Sickle Group; and 4) older gneiss southeast of Notigi Lake with nickel potential.

Introduction

The eastern part of the north flank of the Kisseynew Domain (Zwanzig, 1990) was mapped in the early 1970s and published mainly as a set of 1:50 000 scale geological maps (Baldwin et al., 1979). However, despite this mapping, the structure, stratigraphy and mineral potential of this part of the Kisseynew Domain have remained poorly understood. In addition, recent work in this area has found hitherto unknown Archean orthogneiss and associated paragneiss with Archean provenance, and economic potential that may be similar to that of rocks in the Thompson Nickel Belt (TNB; Percival et al., 2006; Zwanzig et al., 2006).

Notigi Lake is located approximately 100 km west of Thompson along Provincial Highway 391, and along strike from areas that contain rocks now known to be of Archean age or provenance. During the summer of 2007, an area measuring 7 km by 25 km was remapped at 1:20 000 scale. The mapping concentrated on clean shoreline exposures along the eastern part of Notigi Lake (Murphy and Zwanzig, 2007). The work was undertaken to delineate stratigraphic units in detail and to start a structural interpretation that, after further work, will cover a total of about 350 km^2 (Figure GS-5-1).

Previous mapping in the Notigi Lake area by the Manitoba Geological Survey began in 1969 during the Southern Indian Lake Project (Elphick, 1972; Schledewitz, 1972) and was completed during the Burntwood Project (Baldwin et al., 1979). Mapping of the Notigi Lake area (Figure GS-5-2) was carried out by Frohlinger in 1971 and 1973 (Frohlinger, 1979). The emphasis during the Burntwood Project was to distinguish and map the pelitic to psammitic gneiss (present Burntwood Group), the quartzofeldspathic paragneiss (Sickle Group) and the associated intrusive rocks, in order to determine the mineral potential of the Kisseynew Domain. Although subdivisions of the Sickle Group were delineated locally, this was not done at Notigi Lake, nor was Archean rock identified.

Manitoba Hydro completed the Churchill River Diversion in 1977 and redirected water from the Churchill River south along the Rat River through Notigi Lake into the Burntwood River. Notigi Lake was flooded to its present level and, in the process, new clean shoreline exposures were developed. The present project captures structural data and geological contacts from the original Burntwood Project mapping, which was undertaken on pre-flooding shoreline outcrops, and combines this information with remapping of the Sickle Group and adjacent parts of the Burntwood Group at the present lake level.

This project has been undertaken in collaboration with the Geological Survey of Canada as part of the Targeted Geoscience Initiative III (TGI-3) Flin Flon Project (Percival et al., 2006; Percival et al., GS-7, this volume). The purpose of the work at Notigi Lake is to define the tectonostratigraphy, structural geology and tectonic history of an accessible and well-exposed area on the eastern part of the north flank of the Kisseynew Domain. Future work and interpretation will involve additional mapping (2008), as well as geochemical and isotopic analysis of the granitoid intrusions, amphibolite and sedimentary rocks. A new aeromagnetic survey (Coyle, pers. comm., 2007), which will be available by next field season, will provide additional data to assist mapping.

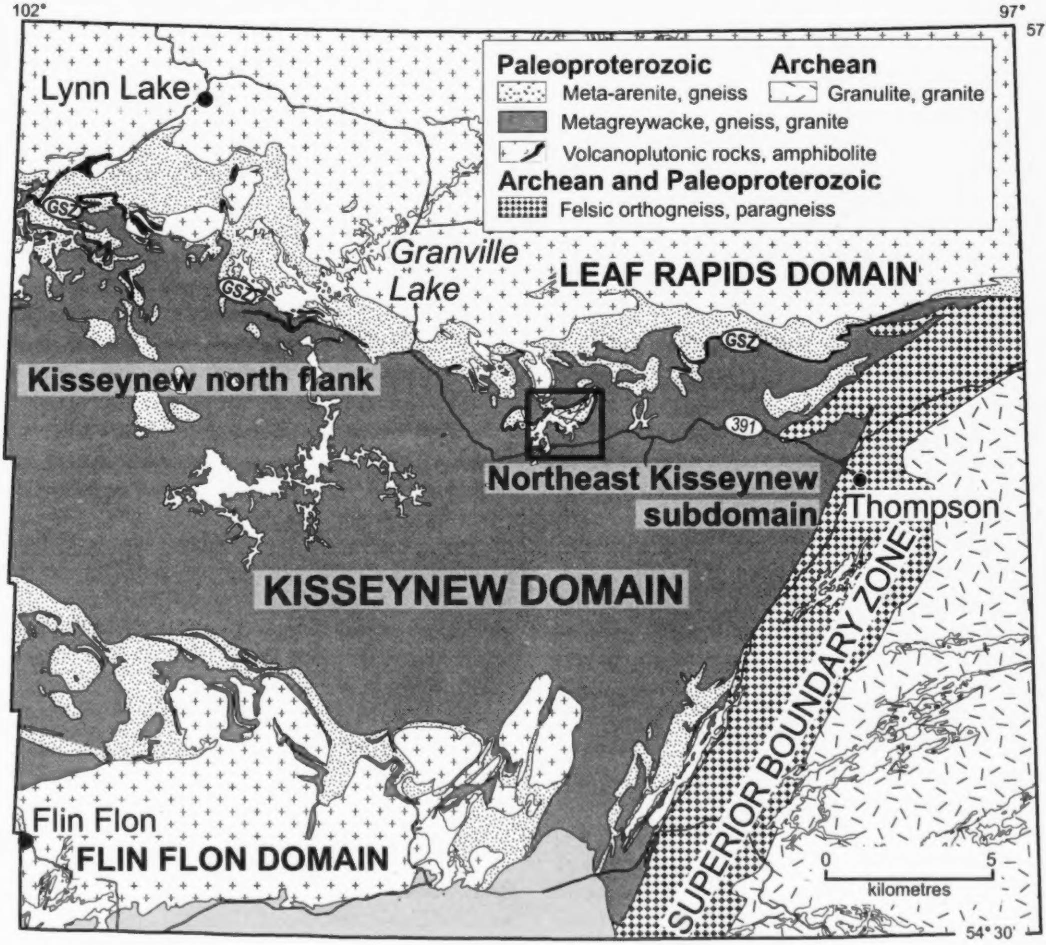

102°
97°
57°
Paleoproterozoic
Archean
Meta-arenite, gneiss
Granulite, granite
Metagreywacke, gneiss, granite
Volcanoplutonic rocks, amphibolite
Archean and Paleoproterozoic
Felsic orthogneiss, paragneiss
Lynn Lake
GSZ
GSZ
Granville Lake
LEAF RAPIDS DOMAIN
GSZ
Kisseynew north flank
391
Northeast Kisseynew subdomain
Thompson
KISSEYNEW DOMAIN
SUPERIOR BOUNDARY ZONE
Flin Flon
FLIN FLON DOMAIN
0
5
kilometres
54° 30'

Figure GS-5-1: *Simplified geology of the northeastern Kisseynew Domain, showing the project location.*

Regional setting

The north flank of the Kisseynew Domain is dominated by high-grade metasedimentary rocks and migmatite of the Burntwood and Sickle groups, generally with a thin intervening unit of amphibolite. Burntwood Group rocks are derived from greywacke, siltstone and mudstone deposited by turbidity currents (Bailes, 1980; Zwanzig, 1990), and the Sickle Group rocks from lithic arenite and arkose deposited in a shallow-water environment (Milligan, 1960). The amphibolite is derived from mafic volcanic rocks (Tod Lake basalt) and associated mafic intrusive rocks. This mafic assemblage is better preserved at Granville Lake and the southwest end of the Lynn Lake belt (Figure GS-5-1), where it is interpreted to have formed during an episode of arc-rifting and back-arc magmatism at about 1.9 Ga (Zwanzig et al., 1999). Where primary structures are preserved, the mafic assemblage is seen to be unconformably overlain by the ca. 1.84 Ga Sickle Group, and this relationship is assumed to hold for the more highly deformed amphibolite and meta-arenite along the entire north flank of the Kisseynew Domain, including the Notigi Lake area. This assumption infers a thrust fault between the amphibolite and underlying younger (ca. 1.85 Ga) Burntwood Group, and is discussed in more detail in a later section.

Recent reconnaissance and local mapping, geochemistry, geochronology and Nd-isotope work in an area extending from southeast of Notigi Lake to the TNB has revealed the existence of narrow belts of Archean gneiss with a thin supracrustal succession similar to the Ospwagan Group, which hosts the deposits in the TNB (Percival et al., 2005, 2006; Zwanzig et al., 2006). The origin, structure and extent of these older rocks in the predominantly greywacke-derived migmatite of the northeastern Kisseynew Domain are still poorly understood. The structural style of the Notigi Lake area, with its better known tectonostratigraphy, may serve as a guide for determining the structural style and three-dimensional extent of the older, economically promising rocks.

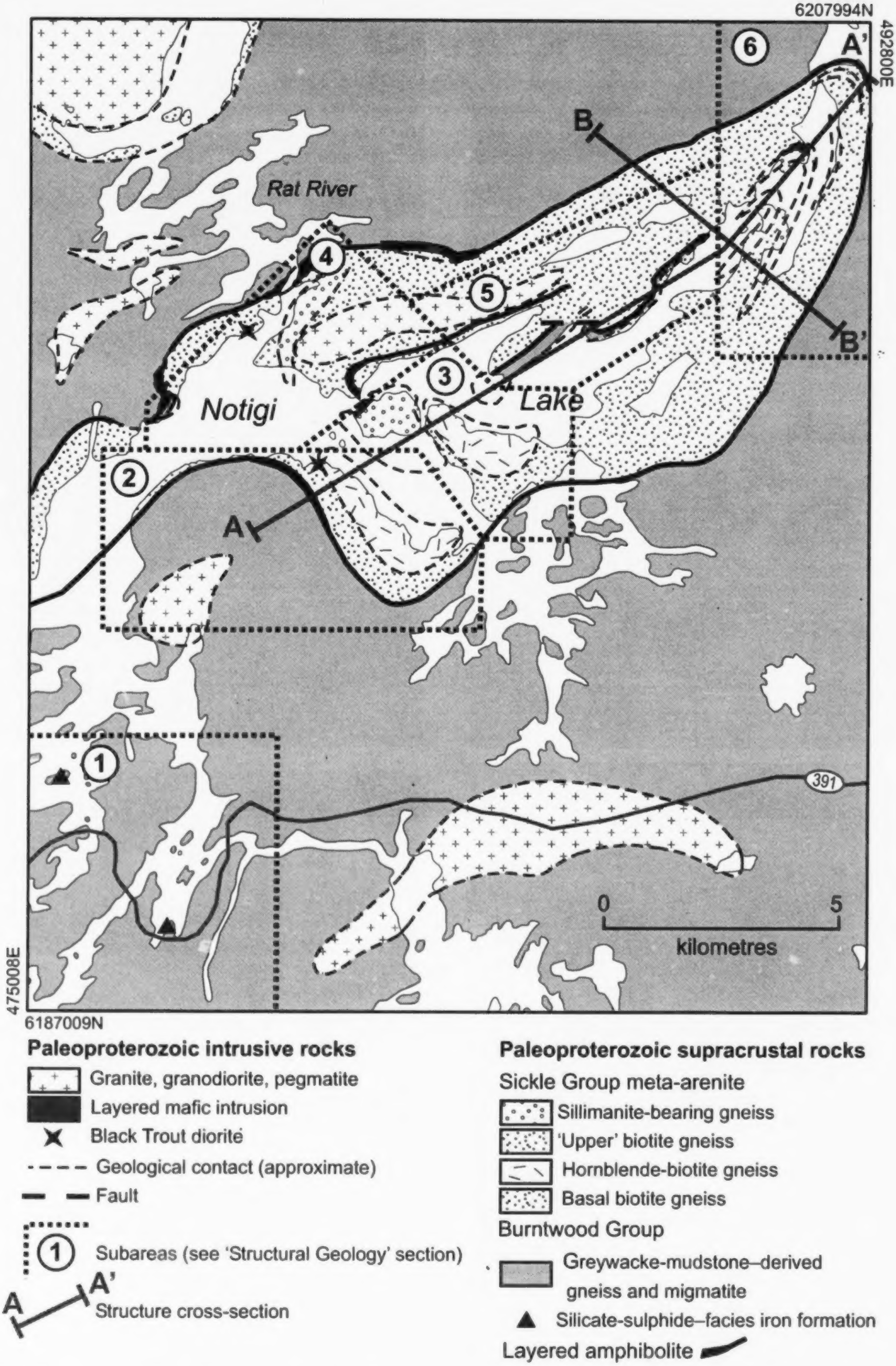

6207994N
492800E
475008E
6187009N
A'
B
B'
A
Rat River
Notigi
Lake
1
2
3
4
5
6
391
0
5
kilometres
Paleoproterozoic intrusive rocks
Granite, granodiorite, pegmatite
Layered mafic intrusion
Black Trout diorite
Geological contact (approximate)
Fault
Subareas (see 'Structural Geology' section)
Structure cross-section
Paleoproterozoic supracrustal rocks
Sickle Group meta-arenite
Sillimanite-bearing gneiss
'Upper' biotite gneiss
Hornblende-biotite gneiss
Basal biotite gneiss
Burntwood Group
Greywacke-mudstone–derived gneiss and migmatite
Silicate-sulphide–facies iron formation
Layered amphibolite

***Figure GS-5-2**: Updated map of the Notigi Lake area, incorporating data from Frohlinger (1979) with recent hydrology and geology from fieldwork in 2007. Subareas mentioned in the 'Structural geology' section are indicated by dashed lines.*

Geological units

The main supracrustal units at Notigi Lake are 1) layered amphibolite with local calcsilicate rock; 2) the Burntwood Group migmatite, derived from greywacke-mudstone with minor iron formation; and 3) quartzofeldspathic paragneiss of the Sickle Group. The stratigraphic order of these units cannot be determined in the study area, but the structural order is the same as in the regional setting and, by correlation, is inferred to be Burntwood Group–fault–amphibolite–unconformity–Sickle Group. The amphibolite is inferred to be the oldest unit, and the Sickle Group the youngest. No depositional or early fault contacts between the major units are preserved at Notigi Lake.

Subunits in the Sickle Group were mapped using distinct compositional changes defined by their dominant mineralogy. Subunit contacts are gradational and are interpreted to be stratigraphic. These subunits generally appear adjacent to (stratigraphically above) the amphibolite in the following order: 1) basal biotite gneiss; 2) hornblende-biotite gneiss; 3) generally more silicic biotite gneiss that is probably stratigraphically higher in the succession; and 4) sillimanite-bearing arkosic gneiss of uncertain stratigraphic position but most likely forming the uppermost subunit. This lithological assemblage is not consistent because of structural influences. For example, hornblende-biotite gneiss may not appear in the sequence and, in places, sillimanite-bearing gneiss is found at the base along the layered amphibolite and is succeeded by biotite gneiss followed by biotite-hornblende gneiss. Both biotite units are similar in composition and appearance. At one locality, the basal biotite gneiss contains a hematite-bearing meta-arkose that does not repeat elsewhere and is therefore included with the biotite gneiss.

All units in the Notigi Lake area have been metamorphosed to upper amphibolite or transitional granulite facies; the prefix 'meta', although not used in the protolith names, is implied.

Layered amphibolite

Layered amphibolite, up to 20 m wide, lies between the Burntwood greywacke-mudstone and the Sickle arkose-arenite. The amphibolite consists of uniform layers that can grade into discontinuous pods and lenses (Figure GS-5-3a). The mineral content reflects the layering and includes hornblende, plagioclase, orthopyroxene, clinopyroxene and, locally, magnetite, biotite and siliceous carbonate matrix. The layers are dark grey-green to black where the dominant minerals are hornblende-plagioclase, and medium grey-green where dominated by diopside-pyroxene-plagioclase. Siliceous calcsilicate layers are pale green to white. Diopside layers are interpreted as structurally transposed high-grade metamorphic products of epidosite ocean-floor alteration domains, and carbonate in more intense alteration.

In the core of the Notigi structure is a body of layered hornblende-gabbro, with 1 m wide, less mafic layers that contain 60% plagioclase and 40% hornblende and sparse hornblende-rich layers with diopside lenses. The presence of carbonate cement and diopside lenses suggests that this narrow body may be related to the main amphibolite unit, which occurs along strike.

Whole-rock major- and trace-element analysis on a sample of relatively unaltered-looking dark green amphibolite (Table GS-5-1) suggests derivation from a mafic rock similar to the Tod Lake arc-rift basalt. The Tod Lake basalt occurs in the western part of the Kisseynew Domain north flank on the southwest end of the 1.9 Ga volcanic rocks of the Lynn Lake belt (Zwanzig, et al., 1999; Zwanzig, 2000). The arc affinity of Notigi Lake amphibolite is illustrated in a normal mid-ocean-ridge basalt (N-MORB)–normalized multi-element plot by negative Nb and Zr anomalies and a Th spike (Figure GS-5-4). The rift affinity is suggested by its weak fractionation of rare earth elements (REE) and lack of negative Ti anomaly.

Burntwood Group

The Burntwood Group is composed of mostly medium and dark grey, psammitic and pelitic (greywacke-mudstone) layers and lesser concordant iron formation. The contact between rocks of the Burntwood Group and the amphibolite is not directly exposed at Notigi Lake, except along a late fault (Figure GS-5-3b). Biotite schist occurs along shear contacts with a mafic intrusion and the layered amphibolite

Greywacke-mudstone migmatite

All Burntwood Group greywacke and mudstone (Figure GS-5-3c) have undergone high-grade metamorphism and various degrees of migmatization. White leucosome is usually 10–15% of the rock, but can range from 5 to 90%. Progressive melting and injection resulted in metatexite with well-developed *lit-par-lit* layering and more uniform coarser diatexite. Late-stage pegmatite and granitic injections have contributed to the migmatitic layering in some places. The mineral content of the Burntwood Group greywacke-mudstone includes garnet, biotite, cordierite, tourmaline and locally orthopyroxene. Graphite is identified locally. Small 0.5 cm diameter garnets occur ubiquitously in psammite, and larger garnets (up to 2 cm) occur in the pelite. Retrograde metamorphism has, in places, reduced tourmaline to chlorite, pinitized cordierite and partly chloritized the garnet.

Iron formation

Lean silicate-facies iron formation is found in two locations at the south end of Notigi Lake. The units are grey to brown, contain rusty patches and are slightly darker than the surrounding Burntwood greywacke, with which they are locally intercalated. They display similar layering to the greywacke or can form concordant pods

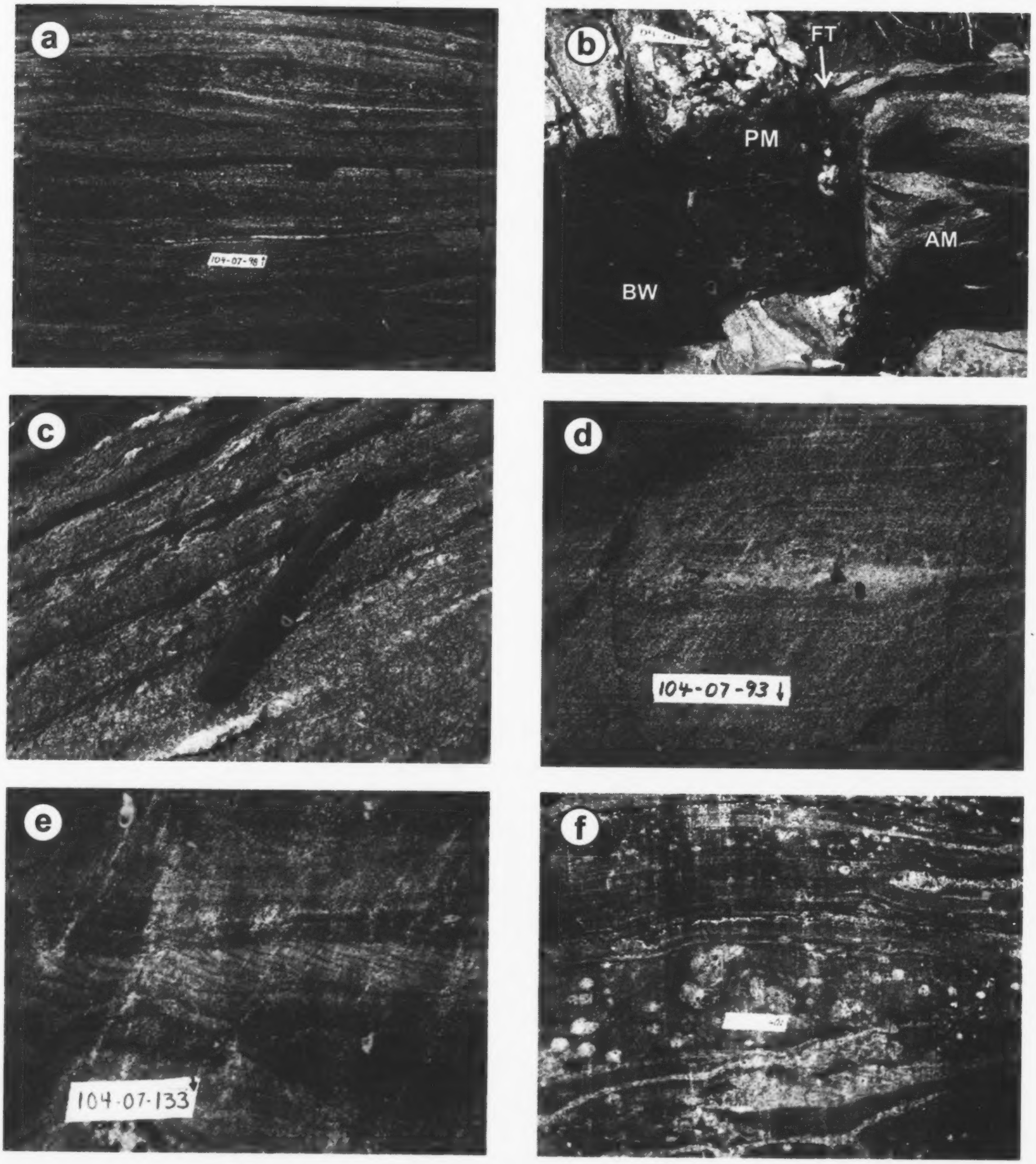


Figure GS-5-3: *Characteristic features of the major units, Notigi Lake area:* ***a)*** *amphibolite with darker hornblende-rich and lighter diopside-plagioclase–rich layers, similar to recrystallized mafic tectonite that can be traced into pillow basalt northeast of the study area;* ***b)*** *pegmatite (PM) along late fault-contact (FT) between the Burntwood Group (BW) and the layered amphibolite (AM);* ***c)*** *Burntwood Group with 2 cm layers of semipelitic gneiss alternating with 1 cm layers of veined pelitic gneiss, interpreted to be derived from turbiditic Bouma divisions of greywacke to mudstone, also with thicker metagreywacke bed (lower right), probably attenuated in the order of 20% of original thickness;* ***d)*** *laminated hornblende gneiss derived from thin-bedded arenite with hornblende blasts in lens of leucosome;* ***e)*** *remnant crossbedding of protoquartzite in biotite gneiss (arenite) at margin of sillimanite-bearing unit;* ***f)*** *quartz-sillimanite faserkiesel (light ovals) in arkose gneiss. Tape is 9–10 cm long and pencil magnet 12 cm long.*

Table GS-5-1: Whole-rock major- and trace-element analyses of layered amphibolite (hornblende-plagioclase layer), calcsilicate gneiss (probably altered layered amphibolite) and monzodiorite (Black Trout diorite), Notigi Lake area.

	Sample (12-06-)		
	162-4	162-3	160-1
	%	%	%
SiO_2	47.3	48.2	49.8
Al_2O_3	12.70	13.28	12.82
Fe_2O_3	13.50	4.98	14.41
MnO	0.23	0.15	0.20
MgO	3.54	1.52	4.34
CaO	14.87	18.23	7.38
Na_2O	2.25	1.14	2.49
K_2O	0.32	3.81	2.30
TiO_2	1.94	2.41	3.01
P_2O_5	0.33	0.40	2.20
LOI	1.87	4.90	0.29
Total	98.83	99.03	99.21
	ppm	ppm	ppm
Sc	42	36	27
Be	2.0	2.0	2.0
V	468	411	264
Cr	<20	<20	<20
Co	38	42	32
Ni	20	30	20
Cu	300	10	20
Zn	110	90	80
Ga	21	24	24
Ge	1.1	0.9	1.0
Rb	4	49	57
Sr	220	180	549
Y	36.5	42.9	58.0
Zr	86	175	473
Nb	4.5	10	27
Sn	1	2	2
Sb	< 0.2	5.8	0.9
Cs	< 0.1	0.9	1.1
Ba	220	541	1575
La	8.72	11.6	123
Ce	22	32.6	267
Pr	3.29	4.98	33.9
Nd	15.3	24.7	129
Sm	4.46	6.3	22.4
Eu	1.71	1.67	5.07
Gd	5.14	6.58	16.6
Tb	0.95	1.19	2.20
Dy	6.02	7.17	11.6
Ho	1.24	1.43	2.10
Er	3.56	4.06	5.30
Tm	0.529	0.588	0.75
Yb	3.40	3.84	4.70
Lu	0.537	0.585	0.68
Hf	2.7	5.0	10.4
Ta	0.26	0.57	1.50
W	6.3	1.6	< 1
Tl	< 0.05	0.28	0.3
Pb	< 5	6	27
Th	1.31	2.26	6.8
U	0.64	0.87	0.90
La/Yb	2.6	3.0	26.2

12-06-162-4: layered amphibolite

12-06-162-3: layered calcsilicate

12-06-160-1: Black Trout diorite

1.5 m in width. The mineralogy of the iron formation indicates alternating greywacke layers, cherty layers and layers laminated with pyrrhotite, magnetite and rare chalcopyrite.

Biotite schist

Biotite schist occurs almost exclusively along the sheared contact between the Burntwood greywacke and the layered amphibolite. The unit is grey-brown to black and, along with the dominant biotite, may contain very small, sparse garnets, muscovite and magnetite. The rock is interpreted as a recrystallized shear zone.

Sickle Group

The Sickle Group is composed of quartzofeldspathic paragneiss generally containing magnetite. Much of the Sickle Group, particularly the biotite gneiss, is relatively massive with no migmatitic layering. Locally, the biotite- and sillimanite-bearing gneiss can exhibit thin pink or white layers of granitic leucosome. Thicker sheets of granite occur locally. The different styles of migmatite in the Sickle and the Burntwood groups reflect their difference in composition, the thickness of original beds and the more massive structure of the arenite.

Basal biotite gneiss

The basal arenite-derived biotite gneiss varies in weathering colour from light to medium grey and brown to reddish brown and can rarely have up to 60% pink to reddish leucosome. The unit varies in appearance from a

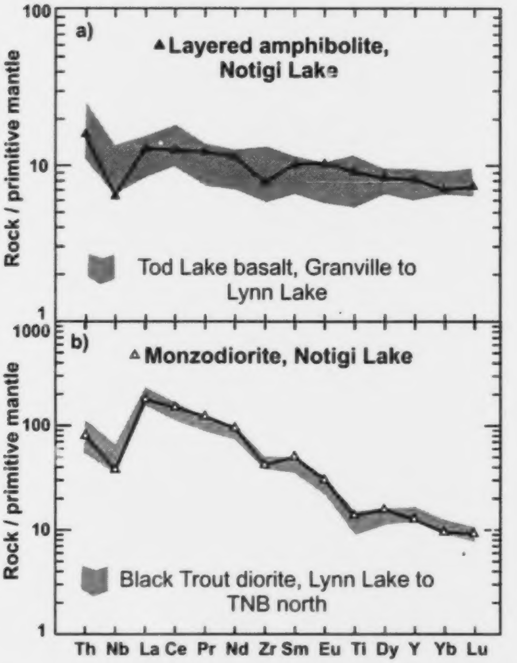


Figure GS-5-4: *Multi-element plots of rocks from the Notigi Lake area, normalized by primitive mantle:* ***a)*** *layered amphibolite, also showing the field of Tod Lake basalt; and* ***b)*** *monzodiorite, also showing the field of Black Trout diorite.*

very fine grained and uniform arenite to thin-bedded (at centimetre scale). coarser grained, more felsic paragneiss. It can be sheared and present as biotite-rich rafts of restite within pegmatitic granite.

The mineral content of the basal biotite gneiss includes quartz, feldspar and magnetite, with local cordierite, tourmaline, garnet, epidote, diopside, muscovite, sillimanite, hematite and rare malachite. Magnetite is moderately abundant (up to 10%) as subhedral crystals that range up to 3 cm and can occur in 10 cm clusters that may have formed, in part, from original placers. In places, the basal biotite gneiss is coarsely recrystallized near granitic intrusions.

The unit can be interleaved with magnetite-free garnet-biotite gneiss, possibly derived from greywacke. More commonly, it is interlayered with hornblende-biotite gneiss. The lower part of the basal biotite gneiss may contain garnet and sillimanite and is locally sheared. The faserkiesel in the lower section are composed mainly of plagioclase rimming magnetite cores up to 3 mm wide. Retrograde metamorphism is locally present in the sheared rocks and manifest as chloritization of biotite and muscovite replacement of sillimanite.

Hornblende-biotite gneiss

The hornblende-biotite–bearing arenite weathers greenish grey to pink. Massive grey varieties, which are locally laminated with a green and pink mesosome, generally contain up to 15% pink leucosome. The mineral content of the hornblende-biotite gneiss includes quartz, feldspar, diopside, tourmaline and magnetite, although generally less magnetite than the other subunits. Amphibole is present in both mesosome and leucosome (Figure GS-5-3d). Diopside is enriched in certain layers and in cores of hornblende-rich lenses that occur sporadically in the leucosome.

Hornblende-biotite gneiss is everywhere interlayered with hornblende-free biotite gneiss. Uniform layers of hornblende biotite gneiss are up to 2 m wide and tend to be fine grained. Coarser arkosic gneiss, by contrast, is thinly bedded (0.5–10 cm).

'Upper' biotite gneiss

The biotite arenite gneiss that lies closer to the centre of the Notigi structure ('upper' biotite gneiss) weathers from light to medium grey, brown and pink, and can have up to 10% pink to red leucosome; rarely, up to 80% of the rock is injected granite. The unit is very fine grained and uniform. Although similar to the basal biotite gneiss in appearance and main mineral content, the different stratigraphic position of this unit is indicated by the structure of the area. The structural complexity is discussed below. The 'upper' biotite unit is interleaved with the hornblende-biotite gneiss. Closest to the core of the Notigi structure, it is interlayered with the sillimanite-bearing gneiss.

Sillimanite-bearing gneiss

Sillimanite-bearing gneiss, which is interpreted to have been derived from arkose, is mostly light grey to grey and pink in colour, and may have up to 40% leucosome. The largest domain of this unit, located in the central to northern part of the map area, is inferred to be the uppermost part of the Sickle Group. The rock is generally rich in quartz and feldspar, and locally interbedded with light grey protoquartzite. The unit varies from having centimetre-scale uniform layering to millimetre-scale biotite-rich laminae. Recrystallization has obscured nearly all primary textures other than transposed bedding (i.e., layering) and, at one location, remnant crossbeds in the protoquartzite (Figure GS-5-3e). These beds are overturned with tops to the south, consistent with the general structural interpretation (*see* below). The sillimanite in this unit reflects local concentrations of alumina, probably from an original clay component, which later generated faserkiesel up to 2 cm in diameter, formed by sillimanite and quartz knots and, in places, plagioclase-feldspar rimming magnetite cores. The faserkiesel are concentrated within certain beds (Figure GS-5-3f).

Intrusive rocks

Mafic and intermediate intrusive rocks

Two exposures of mafic rocks within the Sickle

Group sillimanite gneiss are distinctly coarser grained than the layered amphibolite at the base of the Sickle, indicating an intrusive origin. The exposures are widely separated but at the same stratigraphic level in the central and northeastern parts of Notigi Lake. Both contain dark green to black layers that suggest fractionation in separate sills or possibly in a long single sill.

The central occurrence is up to 20 m wide, with layering composed of four separate rock types that grade into one another: 1) coarse-grained garnetiferous and biotite unit, 2) hornblende-rich unit that grades to less hornblende; and 3) plagioclase-rich unit up to 1.5 m wide and containing up to 60% plagioclase at the top; overlain by 4) darker amphibolite. Layers are thick and internally uniform, and are interpreted to result from crystal fractionation. The zonation of units in this amphibolite body, if due to fractionation of a sill, indicates that it tops to the northeast.

The occurrence in the northeastern part of Notigi Lake has similar layering to that in the central part but also contains garnet-bearing lenses and a trace of carbonate. The relationship between the two occurrences is uncertain but may be resolved by additional structural analysis and petrology.

A biotite-rich monzodiorite unit up to 8 m wide intrudes the Sickle Group on the west side of the Rat River channel. This is an extension of the Black Trout diorite that extends from Granville Lake (Zwanzig and Cameron, 2002) to areas southeast of Lynn Lake (Milligan, 1960) and is interpreted to extend into an area north of Notigi Lake. The unit contains abundant magnetite and titanite, and displays a uniform schistosity. Its geochemistry is transitional to alkaline and characterized by high contents of K_2O, Na_2O and P_2O_5, with a high La/Yb ratio at relatively high MgO and TiO_2 (Table GS-5-1). On a multi-element plot (Figure GS-5-4b), it shows a distribution of elements identical to that shown by the type Black Trout diorite.

Granitic intrusive rocks

Granite intrusion and pegmatite

All units in the Notigi Lake area have been injected by granite and pegmatite sheets. The granitoid rocks intruding Burntwood greywacke in the southern part of the map area range from white plagioclase-rich tonalite to leucogranite. Several ages of pink to red pegmatite have been injected as sheets into all units. Minor minerals of note in both granite and pegmatite include cordierite, tourmaline, biotite, muscovite, garnet and magnetite. Retrogressive metamorphism can be identified by cordierite replaced by garnet+chlorite and biotite replaced by chlorite.

North of Timew Narrows, a large granite intrusion (Notigi granite) that cuts mainly Sickle Group rocks is in local contact with the layered amphibolite unit. It is a pink feldspathic rock with a biotite parting.

Structural geology

In this report, structural geology is described for six geographic subareas distributed around Timew Narrows, at the centre of Notigi Lake, each illustrating different aspects of the structure (Figure GS-5-2). Explaining the differences in structural style, trends and ages in these subareas provides a preliminary interpretation of the entire Notigi structure and has a bearing on the regional structure. Preliminary interpretations indicate that large-scale regional folding has occurred throughout the Notigi Lake area, with faults and shears disrupted and overprinted on a regional northeasterly trend. Future traverses to key locations will refine the preliminary interpretations presented in this report.

The structural interpretation assumes that, like farther west on the north flank of the Kisseynew Domain, an early (D_1) fault forms the contact between the Burntwood Group and the amphibolite unit. Recumbent and moderately inclined folds and foliation are considered to have developed during D_2 (Figure GS-5-5a, b) but, due to strong D_3 folding and flattening on the northeasterly trend, the foliation formed initially during D_2 now trends northeast and is typically a composite S_{2-3} fabric. Abundant mineral and intersection lineations occur in F_3 hinge areas where there is interference with the F_2 folds and foliation. Evidence that some F_2 folds were recumbent or small fold nappes is in the shallow plunge of the major F_3 fold in some central parts of the lake and at its northeast end. A curved northeast-steepening hinge line, together with the steep hinge in the southwest and general outward dip of the foliation, indicates that the major F_3 Notigi structure is domal. Late faults (D_4), although not exposed, are inferred from structural complications involving F_{2-3} crossfolds.

Subarea 1

Subarea 1 encompasses the south end of Notigi Lake in the Burntwood Group migmatite. Layering with boudinaged and folded leucosome exhibits the D_3 regional northeast trend or is partly transposed into that trend (Figure GS-5-5c). The dip changes from steeply west-northwest in the southeast to steeply southeast in the northeast. Linear fabric and minor folds plunge southwest, but this changes to northeast at the south end of the lake. This geometry suggests the presence of a large-scale F_3 synform with a variable plunge.

Subarea 2

Subarea 2 is centrally located in Notigi Lake, south of Timew Narrows, and includes the Burntwood Group migmatite, the layered amphibolite and Sickle arenite. The subarea exhibits north-northeast-trending folds. The Sickle Group rocks display good structural information, including layering, mineral and intersection lineations,

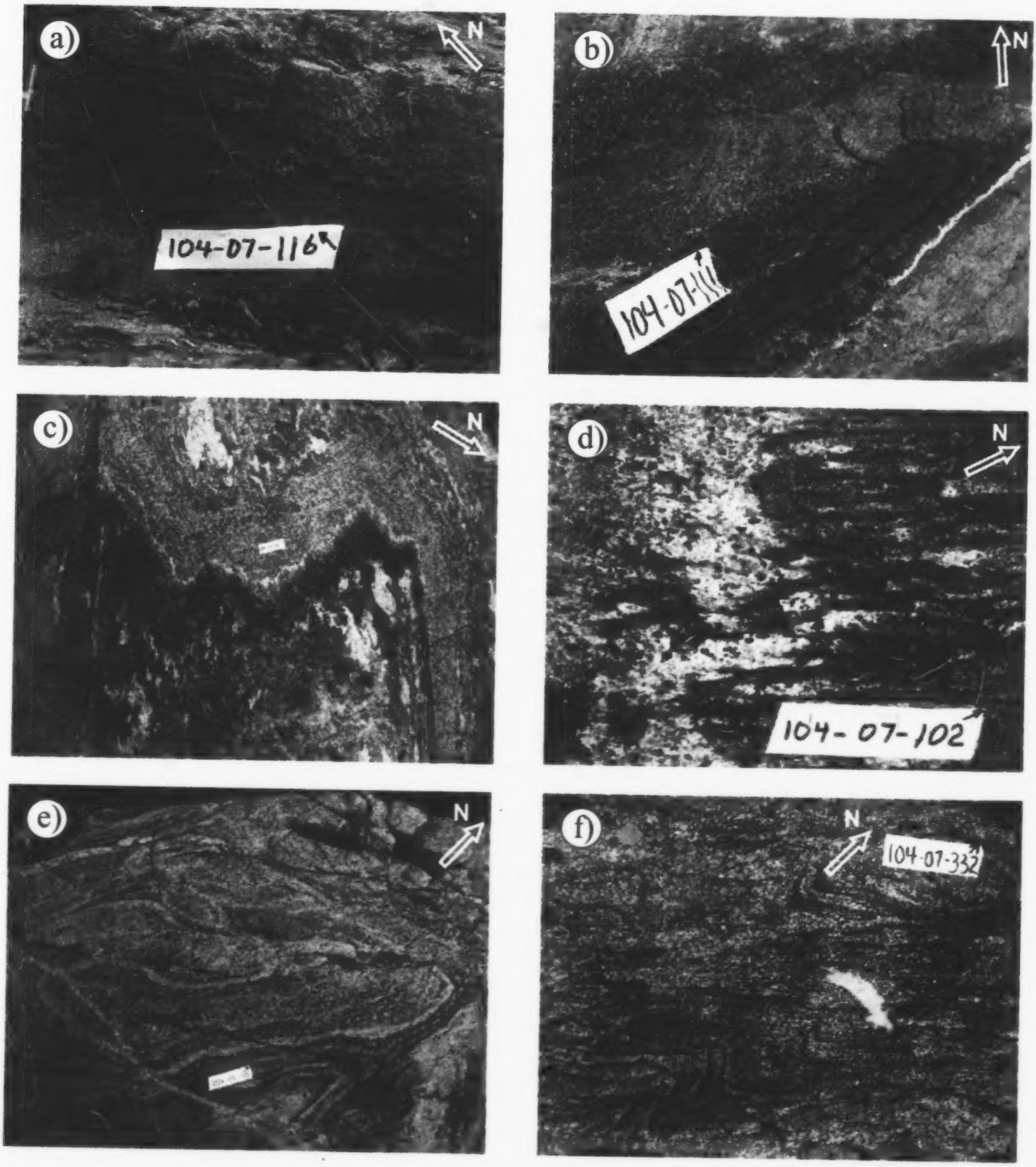


Figure GS-5-5: *Field photographs of structural features in the Notigi Lake area:* ***a)*** *gently east-dipping bedding cut by gently north-dipping* S_2 *foliation (parallel to tape) most noticeable in biotite-rich bed (under tape), looking northeast at steep rock face;* ***b)*** *minor* F_2 *recumbent fold (bedding contacts marked by solid line) and axial-planar* S_2 *foliation (dashed line), looking north and down at stepped face;* ***c)*** *bedding, leucosome veins and* S_2 *foliation partly transposed along northeast-trending* F_3 *folds,* S_3 *foliation and a* D_3 *shear; note how irregular leucosome pods line up along* S_2*, having formed parallel to bedding and possibly* S_1 *cleavage;* ***d)*** *gently northeast-plunging rodding produced by constriction and stretching along* S_2*-*S_3 *intersection;* ***e)*** *minor domal structure in thin bedding and foliation (west of tape), interpreted as northeast-trending* F_3 *fold interfering with east-trending* F_2 *fold;* ***f)*** *late* F_3 *or* F_4*, north-northeast-trending minor folds with chevron style typical of high-level structures, suggesting uplift after* D_2*. Tapes are 9–10 cm long.*

and rodding (Figure GS-5-5d). The unit also contains L-tectonite and pseudotachylite. Map-scale structures are a pair of open F_3 folds with north-northeast-trending axial surfaces. They form a steeply south-plunging synform in the west and a gently north-plunging synform in the east. Minor F_2 structures with shallow-dipping foliation (S_2) and axial surfaces (F_2) are preserved in the core of the eastern F_3 fold (Figure GS-5-5a, b). This suggests that F_2 was recumbent before refolding.

Subarea 3

Subarea 3 includes the island at Timew Narrows and farther east. The layered mafic intrusion and the sillimanite and biotite gneiss display structures that differ from the more typical, north-northeasterly F_3 trends found elsewhere on the lake. The trends in subarea 3 are broadly east-west with highly variable dips. Lineations plunge at 10–27° toward the north and northeast.

The area contains the continuation of the map-scale F_3 fold pair in subarea 2, but a reversal in plunge is indicated by changes in the northeast dip of the layering. This is probably due to the presence of a tight, map-scale F_2 syncline that closes to the south. The interpretation is supported by a reversal in stratigraphic sequence, which is upright in subarea 3 and overturned farther to the northeast. Therefore, the highest stratigraphic unit (sillimanite-bearing gneiss) occurs in the core of the F_2 structure. The presence of this structure is consistent with the northeast-topping sill on the south side of the sillimanite-bearing gneiss, and a south-topping sequence (overturned), indicated by crossbedding, on the north side of the gneiss. The area also contains examples of minor fold interference (Figure GS-5-5e). Relatively young faults may have further disrupted the structure north and east of the island, but further work is required.

Subarea 4

Subarea 4 extends north and west of Timew Narrows to the Rat River channel. It encompasses Burntwood migmatite, layered amphibolite, Notigi granite and Sickle gneiss; internal boundaries are yet to be mapped in the latter. The layered amphibolite crosses both sides of the Rat River channel on the northeast side of the large-scale Notigi structure. Dips are dominantly northeast in a highly attenuated succession. A late (D_4) sinistral fault is inferred on the west side of the channel.

Subarea 5

Subarea 5 is located along the north shore of the eastern part of the lake. The area forms the core of the Notigi structure and is underlain by Burntwood greywacke, the layered amphibolite, and both biotite- and sillimanite-bearing gneiss of the Sickle Group. The greywacke and overlying amphibolite occur in two narrow northeast-trending belts surrounded by the Sickle Group. This upright succession is tentatively interpreted as a structural window exposing the F_2 under-limb of the Notigi structure in the core of the main F_3 fold (Figure GS-5-6).

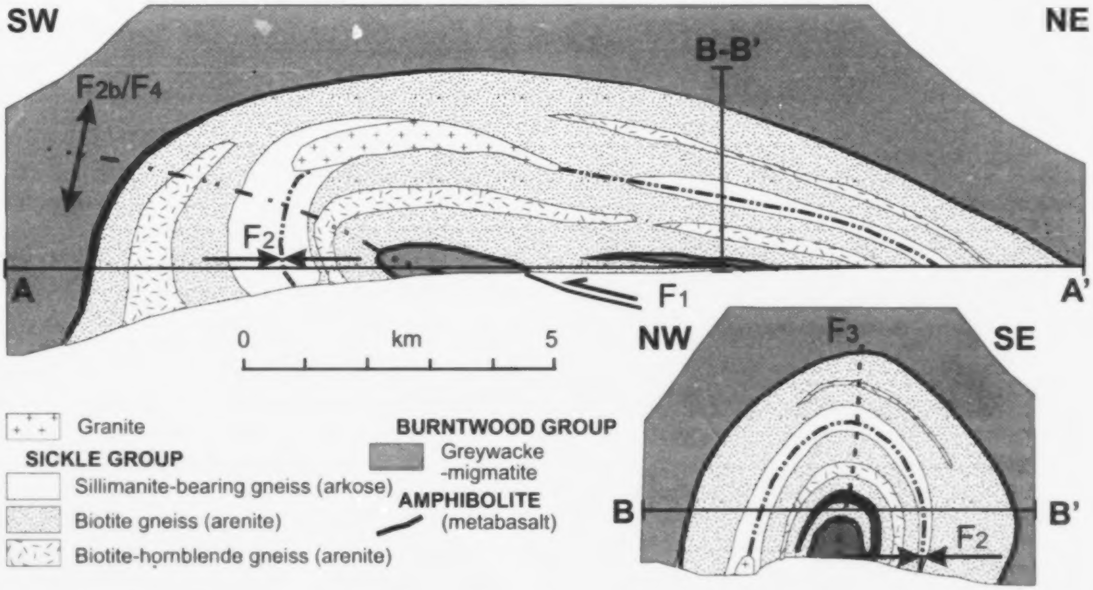


Figure GS-5-6: *Highly simplified vertical sections of the Notigi structure, showing the repetition of units across a major S_2 syncline that experienced complex refolding. The oldest units (amphibolite and Burntwood Group greywacke-migmatite) in the core and above the structure indicate that the large F_2 fold was recumbent before the refolding. Section* ***A–A'*** *has the observer looking northwest at a possible southerly-verging, gently inclined F_{2b} or F_4 antiform traced out by the F_2 hinge line. Section* ***B–B'*** *has the observer looking northeast at the tight F_3 antiform.*

A third narrow belt of layered amphibolite occurs along part of the southeastern contact of the Notigi granite. Its stratigraphic and structural position is as yet unknown. Repetition of the tight fold cores may be due to northeast-trending upright folds and shears, identified at small scales as late D_3 (Figure GS-5-5f).

Subarea 6

Subarea 6 is located at the northeast end of Notigi Lake. The area includes the Burntwood greywacke, a thin gabbroic unit and a complete section through the Sickle Group. The area contains both upright and inverted stratigraphic sequences, with a narrow unit of sillimanite-bearing gneiss in the core of the F_2 syncline refolded in the hinge zone of the F_3 Notigi structure. Mineral and intersection lineations vary in plunge from 6 to 16° in the southwest, and from 22 to 52° in the northeast. The northerly increase in plunge and the outward dip of the limbs shows that the northeastern part of the major F_3 structure is domal.

Structural interpretation and regional implications

The new mapping and the early work in the vicinity of Notigi Lake indicate that the overall shape of the Notigi structure is an asymmetric dome with a moderately plunging northeasterly closure and a steeply dipping southern margin. This geometry may have formed by noncylindrical, northeast-trending, F_3 upright folding superimposed on a large, recumbent F_2 synform. Another possible origin involves gentle F_4 refolding of the F_3 hinge on an east-west trend, but no related fabrics or minor structures were observed. It is also possible, alternatively, that a late F_2 south-verging anticline has caused the curved hinge line and an inherited asymmetry of the later dome. This last interpretation is most consistent with the preliminary structure section (Figure GS-5-6).

The tight or isoclinal F_2 folding has caused repetition of the Sickle Group stratigraphic sequence in a vertical stack that was later involved in possible F_{2b} reclined folding and the F_3 doming. The Burntwood Group and layered amphibolite, overlain by the lowermost (upright) succession of the Sickle Group, is interpreted to be a structural window. Therefore, the Burntwood Group overlies and underlies the sheet-like F_2 structure. If the F_2 synclinal closure is to the south, as suspected, tectonic transport was north and consistent with the occurrence of (inverted) Burntwood Group in structural basins north of Notigi Lake (Schledewitz, 1972). Fold vergence was reversed to a southerly direction during later (F_{2b} and/or F_4) folding.

The best indication of a regional F_1 thrust contact between the Burntwood Group and the layered amphibolite is the correlation of the latter with the inferred 1.9 Ga (allochthonous) Tod Lake basalt. The correlation is based on the geochemistry of the amphibolite and its alternating hornblende- and diopside-rich components that are formed from pillow structure and prominent calcsilicate alteration domains. The thin interlayering of these components at Notigi Lake is shared with a mafic tectonite on Granville Lake that was traced along strike into well-preserved Tod Lake pillow basalt. The regional thrust is interpreted as part of the Granville Lake structural zone (Zwanzig, 1990), a crustal suture in which the amphibolite forms a remnant of the upper part of a back-arc ophiolite (White et al., 2000). This zone extends from the Saskatchewan border east for 300 km to an area north of Thompson (GSZ in Figure GS-5-1).

A belt of Sickle Group rocks, up to 25 km wide, lies north of the Granville Lake structural zone, separating it from the Leaf Rapids arc domain. Outliers of the Sickle Group, up to 40 km long and including the 30 km long Notigi structure, occur in the marine basinal terrane of predominantly Burntwood Group gneiss to the south (e.g., Lenton, 1981). The Notigi structure and many of the other outliers contain the same distinctive mappable units in the Sickle Group, and are mantled by the same amphibolite, as in the Granville Lake structural zone. The conversion of pillows and alteration domains into thinly layered mafic tectonite (undivided amphibolite of Zwanzig and Cameron, 2002) argues for an extreme attenuation of the entire tectonostratigraphic package at Notigi Lake and isoclinal folding at a crustal scale in the northern and northeastern parts of the Kisseynew Domain. Archean orthogneiss and associated paragneiss are expected to occupy deeper levels than the Notigi structure but are part of the same crustal-scale layering.

Economic considerations

The updated geological maps provide a modern geological context for future nickel, platinum group element and gold exploration along the north flank of the Kisseynew Domain. The presence of small gold showings in the Tod Lake basalt, south of Granville Lake, make the correlative layered amphibolite at Notigi Lake and in adjoining areas a possible exploration target. Traces of malachite staining in the Sickle Group may indicate a style of mineralization similar to that of the sedimentary copper mineralization reported by Baldwin (1980) at Russell Lake.

The inferred, strongly layered crustal structure in the northeastern part of the Kisseynew Domain has an implication for the geometry of Archean orthogneiss and Ospwagan-like paragneiss that have competency and probable structural style similar to the Notigi structure. The extreme attenuation suggests that the best chance for preservation of such rocks and possible nickel deposits may be in the hinge zones of F_2 recumbent folds brought to surface by F_3 crossfolds.

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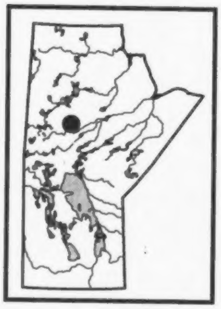
GS-6

Unique amphibolite–iron formation assemblage in the Kawaweyak Lake area, Manitoba (part of NTS 63O15)

by L.A. Murphy and H.V. Zwanzig



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Summary

This report summarizes two weeks of fieldwork carried out during the summers of 2006 and 2007 in the northeastern portion of the Paleoproterozoic Kisseynew Domain. The purpose of the project, which is part of a collaborative Targeted Geoscience Initiative III (TGI-3) project with the Geological Survey of Canada, is to determine whether gneiss equivalent to the nickel-bearing Ospwagan Group, which has an Archean provenance in the Thompson Nickel Belt (TNB), is also exposed within dominantly Burntwood Group greywacke gneiss at Kawaweyak Lake.

Mapping during 2007 showed that the Burntwood Group greywacke gneiss and psammitic to semipelitic units of quartz-rich, calcareous and biotitic gneiss at Kawaweyak Lake are in gradational contact with a distinctive amphibolite–iron formation assemblage. The latter assemblage, which is well exposed at the south end of the map area, can be traced 6 km northeast along strike to the eastern shoreline of Notakikwaywin Lake. A Nd model age of 2.15 Ga on a sample of the semipelite from the quartz-rich rocks at the south end of the Kawaweyak Lake is not consistent with an affinity for the Ospwagan Group, and more consistent with belonging to the juvenile Paleoproterozoic Burntwood Group or an assemblage of amphibolite and siliciclastic rocks that generally overlies the Burntwood Group. The amphibolite has minor gold showings south of Granville Lake, northeast of the map area.

Introduction

The Kawaweyak Lakes area is accessible along Highway 391, approximately 80 km west of Thompson. The study area encompasses a 1.5 km by 6 km strip along the shorelines on Kawaweyak Lake and northeast across a small channel to Notakikwaywin Lake (Figure GS-6-1). The outcrop around the lakes is sparse and shoreline exposures are small but relatively clean.

Mapping in 1971 by Kendrick (Baldwin et al., 1979) indicated that the Kawaweyak Lake area contains greywacke-derived gneiss and migmatite (present Burntwood Group), hornblende-diopside gneiss and pyrite- and pyrrhotite-bearing amphibolite gneiss (originally assigned to the Sickle Group). During the summer of 2006, magnetic highs delineated by an aeromagnetic survey (Coyle and Kiss, 2006) along the Wuskwatim corridor (Percival et al., 2005) were selectively re-examined (Percival et al., 2006; Zwanzig et al., 2006). This was prompted by the hypothesis that rocks similar to those in the Thompson Nickel Belt (TNB), including iron formation, may be exposed farther west of the TNB than previously realized. The geological investigations in 2005 and 2006 indicated that paragneiss with iron formation and orthogneiss of Archean age, similar to units in the TNB, are interleaved with, or lie structurally below, Burntwood Group migmatite. Rocks in the Kawaweyak Lake area were found to include calcareous gneiss, iron formation and metagabbro. Further investigation in 2007, described in this report (Murphy and Zwanzig, 2007), indicates that an assemblage of amphibolite and iron formation and associated quartz-rich and calcareous biotite gneiss at Kawaweyak Lake forms a package that is unusual for the Kisseynew Domain but appears to be unrelated to rocks in the TNB or those in the Wuskwatim corridor. Instead, the package may be part of the Burntwood Group or older Paleoproterozoic rocks, including Tod Lake basalt (Zwanzig et al., 1999), which are better exposed in the northwestern part of the Kisseynew Domain.

Regional setting

The Kawaweyak Lake area is located within the northeastern part of the Kisseynew Domain, bounded by the Leaf Rapids Domain in the north and the TNB in the southeast. It is part of the internal zone of the Paleoproterozoic Trans-Hudson Orogen (Figure GS-6-1). The dominant supracrustal rock of the Kisseynew Domain is the Burntwood Group migmatite gneiss, which is interpreted to have been derived from greywacke-mudstone turbidite deposited within a marine basin (Zwanzig, 1990, 1999). Generally overlying the turbidite is an amphibolite unit, interpreted as arc-related ocean-floor basalt, that extends to the Lynn Lake belt (Tod Lake basalt of Zwanzig et al., 1999; Murphy and Zwanzig, GS-5, this volume). Intrusive bodies in the Kisseynew Domain include foliated tonalite, granite, diorite and late-stage pegmatite. During 1.85–1.83 Ga terminal subduction in the Trans-Hudson Orogen, the basin opened (Ansdell et al., 2005) or closed (Zwanzig, 1999), with local obduction of Tod Lake basalt (White et al., 2000) and deposition of the turbidite and related terrestrial rocks (e.g., Sickle Group). Progressive deformation generated large-scale regional nappe-style folds, refolded by northeast-trending crossfolds (Zwanzig, 1990; Murphy and Zwanzig, GS-5, this volume). Granite and pegmatite intrusion, and

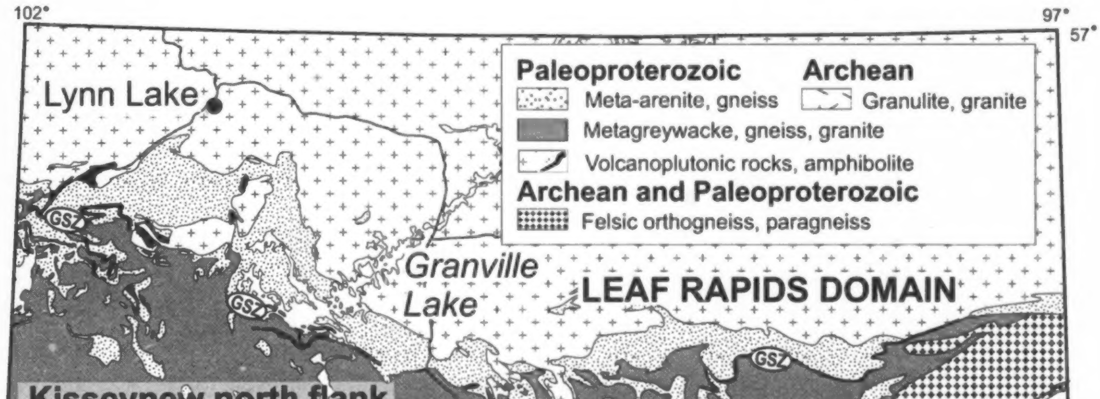
102°
97°
57°
Paleoproterozoic
Meta-arenite, gneiss
Metagreywacke, gneiss, granite
Volcanoplutonic rocks, amphibolite
Archean
Granulite, granite
Archean and Paleoproterozoic
Felsic orthogneiss, paragneiss
Lynn Lake
GSZ
Granville Lake
LEAF RAPIDS DOMAIN
Kisseynew north flank
391
Northeast Kisseynew subdomain
Thompson
KISSEYNEW DOMAIN
SUPERIOR BOUNDARY ZONE
Flin Flon
FLIN FLON DOMAIN
0
5
kilometres
54° 30'

Figure GS-6-1: *Simplified geology of the southeastern part of Trans-Hudson Orogen in Manitoba, showing the location of the Kawaweyak Lake area on the north flank of the Kisseynew Domain.*

metamorphism led to migmatization of the greywacke-mudstone and development of local orthopyroxene and the regional assemblage of garnet-biotite-sillimanite±cordierite. This has produced distinctive grey and white *lit-par-lit* gneiss in the Burntwood Group.

General geology

The map area at Kawaweyak and Notakikwaywin lakes (Figure GS-6-2) includes four main rock assemblages:

1) Burntwood Group gneiss and migmatite
2) interlayered quartz-rich and calcareous biotite gneiss, and semipelitic to pelitic gneiss
3) layered amphibolite and gabbro that are spatially associated with calcsilicate-, silicate-sulphide– and sulphide-facies iron formation, as well as sulphidic biotite gneiss
4) intrusions of granodiorite, granite and pegmatite

They occur from west to east in the following order: Burntwood Group gneiss, followed by biotite-bearing gneiss to calcareous rocks, in turn followed by layered amphibolite or iron formation. Quartz-rich units occur along the margin of this assemblage, adjoining granite and Burntwood Group gneiss.

Many of the contacts between assemblages 2 and 3, and between different rock types within them, exhibit a gradual compositional change. The layered amphibolite and iron formation are also internally gradational, with calcsilicate- and biotite-rich units becoming progressively more amphibole or sulphide bearing. Contacts of assemblages 2 and 3 with the Burntwood Group are not exposed, but the Burntwood Group lies very close to different units along strike and the presence of a major strike fault cannot be ruled out. The intrusive contact between the gabbro unit and the amphibolite–iron formation assemblage may be sharp and have a slight chill zone. The

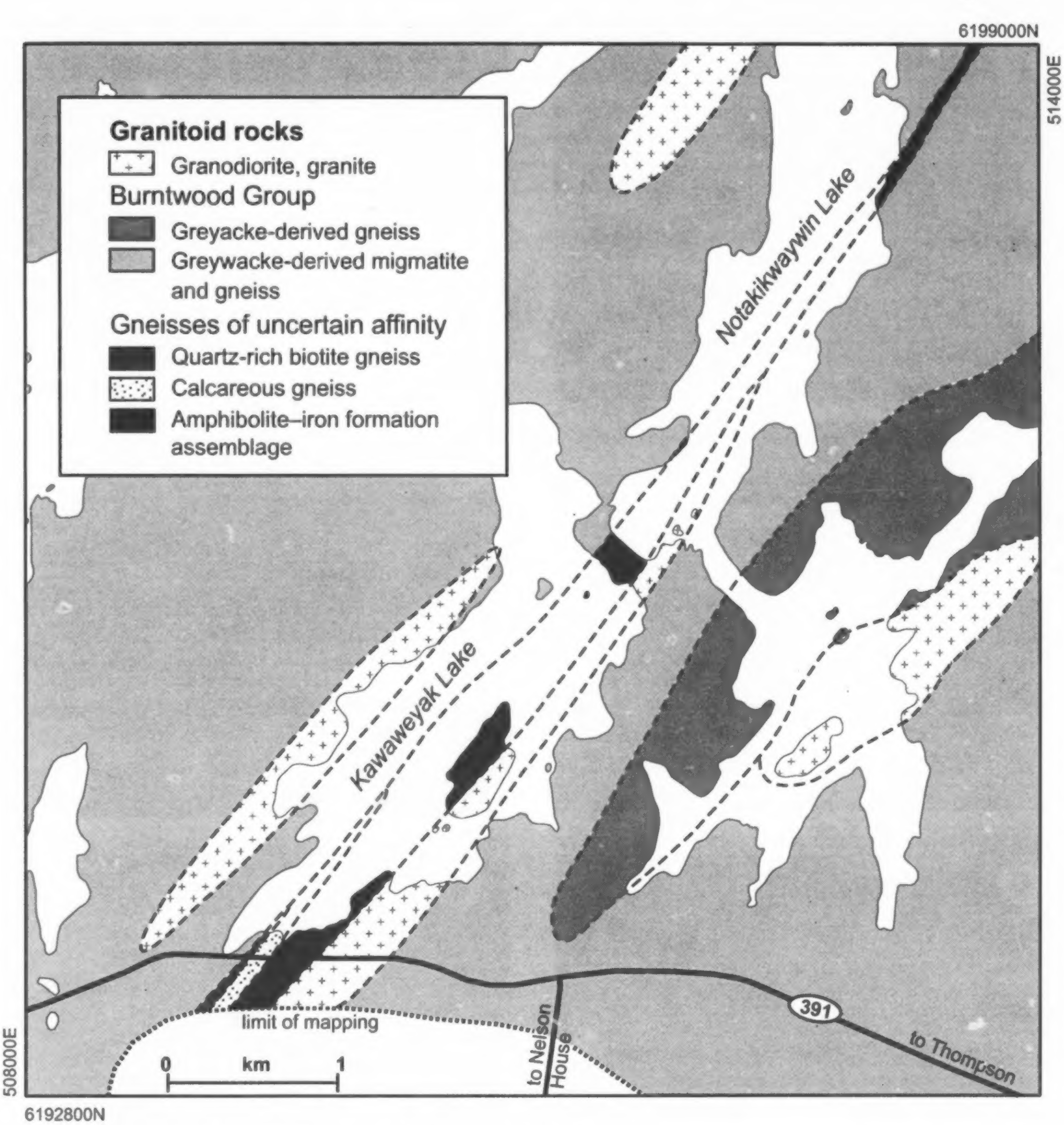
6199000N
514000E
Granitoid rocks
Granodiorite, granite
Burntwood Group
Greyacke-derived gneiss
Greywacke-derived migmatite and gneiss
Gneisses of uncertain affinity
Quartz-rich biotite gneiss
Calcareous gneiss
Amphibolite–iron formation assemblage
Notakikwaywin Lake
Kawaweyak Lake
limit of mapping
0
km
1
to Nelson House
391
to Thompson
508000E
6192800N

Figure GS-6-2: Simplified geological map of the Kawaweyak Lake area.

granodiorite has inclusions of Burntwood Group gneiss, and amphibolite, indicating that these rocks are older than the granodiorite. Granite and pegmatite are the youngest units to have intruded throughout the Kawaweyak Lake area.

Regional metamorphism peaked at the granulite facies and is displayed in mineral assemblages that include garnet, biotite, sillimanite and cordierite, with local orthopyroxene in the Burntwood Group and the gabbro. Retrogressive garnet has partly replaced cordierite in the Burntwood Group gneiss. All rock types are metamorphosed, but the prefix 'meta' is generally omitted from their names.

Burntwood Group

The Burntwood Group migmatite contains up to 20% granitoid leucosome and consists of alternating medium grey to brown layers produced by metamorphism of a greywacke-siltstone-mudstone sequence. Mineralogically, it contains biotite, garnet and cordierite, with smaller garnets and less biotite in psammitic layers (Figure GS-6-3a), and orthopyroxene in fine-grained leucogranite lenses. Retrogressive metamorphism in the leucosome caused replacement of cordierite by garnet.

The contact is not exposed between the Burntwood Group gneiss and the calcareous rock. There are inclusions of the Burntwood Group in the granodiorite unit.

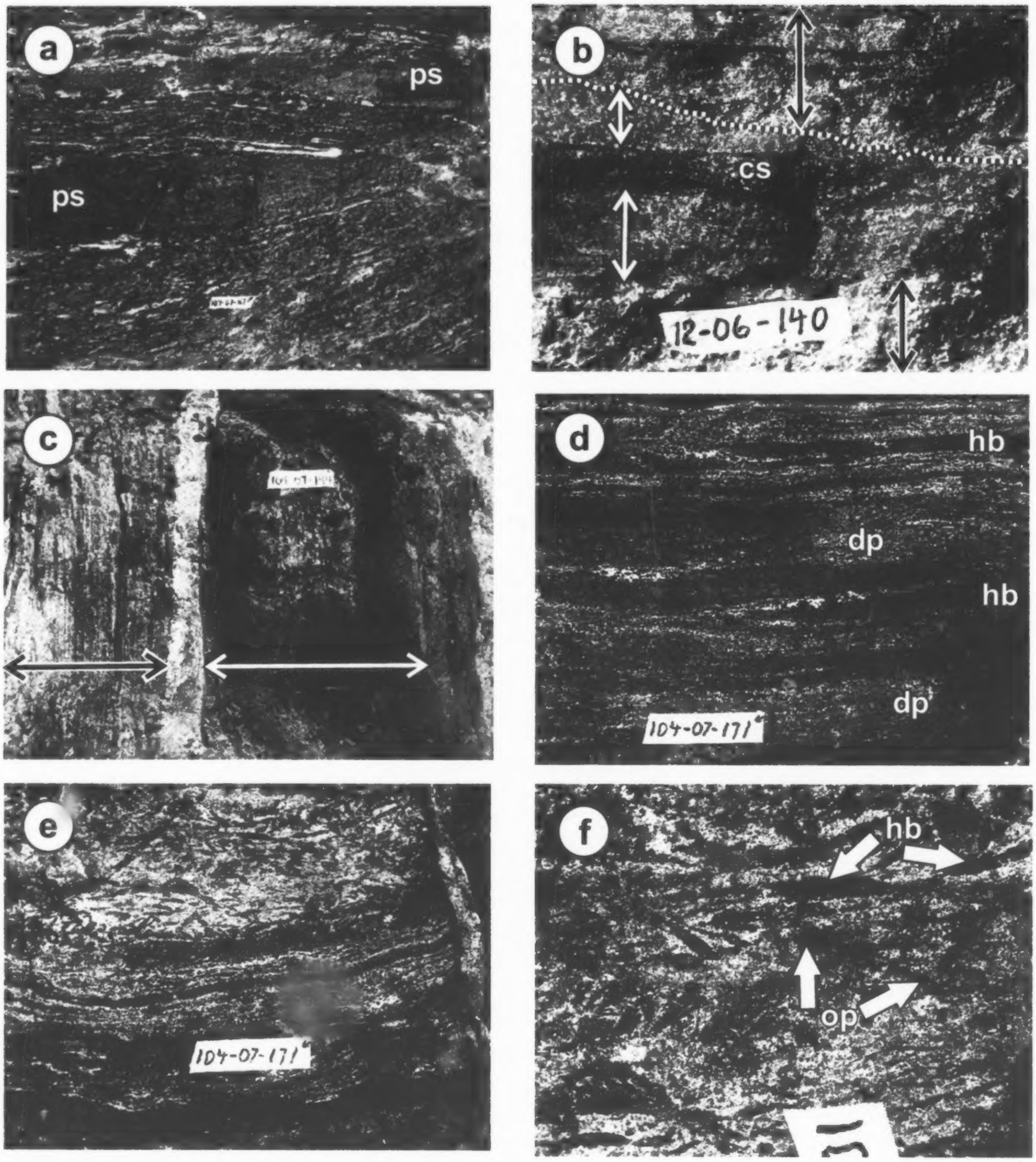

Figure GS-6-3: *Typical supracrustal rocks in the Kawaweyak Lake area, northeastern Kisseynew Domain:* ***a)*** *Burntwood Group gneiss with pelite surrounding psammite lenses (labelled 'ps');* ***b)*** *quartz-rich biotite gneiss (white arrows), with carbonate-bearing interbeds (black arrows) and a thin layer interpreted as calcsilicate (cs); white dotted line marks interlayered beds;* ***c)*** *interlayered iron formation, with black arrow marking the extent of calcareous gneiss on the left and white arrow marking the iron formation on the right, and a late granite dike in the middle; biotite gneiss occurs on the extreme right;* ***d)*** *amphibolite showing alternating hornblende (hb)- and diopside (dp)-rich layers;* ***e)*** *layered amphibolite with metamorphic hornblende and orthopyroxene at the top of the photograph; and* ***f)*** *close-up of bladed hornblende (hb) and equant orthopyroxene (op) in the layered amphibolite. White tape for scale is 9–10 cm long and 2.5 cm wide.*

Quartz-rich and calcareous biotite gneiss

The quartz-rich biotite gneiss is typically grey in colour, but also includes light grey to cream calcite-bearing layers and brown biotite-rich layers. This unit of quartz-rich gneiss is interpreted to have been formed from fine-grained sandstone and siltstone (psammite) with interlayered semipelite to pelite, the latter forming the biotite-rich layers. The carbonate may have originated from calcite cement between clastic quartz and feldspar grains. Glassy grey layers, in this metasedimentary succession, are interpreted as protoquartzite. Layering and interlayering occur at a centimetre scale (Figure GS-6-3b). Quartz and feldspar are the dominant minerals in the gneiss, with lesser biotite, calcite, diopside, garnet and local pyrrhotite. In the southern part of the map area, the western part of the succession contains a relatively thick member dominated by quartz-rich gneiss with only biotite and local garnet.

Neodymium isotope data of a slightly biotite-enriched layer of psammite to semipelite (Table GS-6-1) yielded a Nd model age of crustal residence of 2.15 Ga, indicating that the detritus was derived from a juvenile Paleoproterozoic source similar to the internal zone of the Kisseynew Domain.

Calcareous gneiss

The most prominent calcite-bearing section occurs at the south end of the map area, where up to 8 m are exposed on the east side of the quartz-rich gneiss. The calcite-bearing beds are interlayered with more quartz- and more biotite-rich gneiss (above). The sedimentary section becomes amphibole rich and grades into the amphibolite–iron formation assemblage farther to the east (Figure GS-6-3c). The calcareous gneiss is light grey, with local green calcsilicate interlayers and brown- to rusty-weathering layering that has a higher content of biotite ± iron sulphide. The best exposures display differential erosion, wherein calcareous layers and lenses are recessive. The mineral content of the calcareous layers includes quartz, plagioclase, diopside, calcite, pyrrhotite and, possibly, scapolite. Layers can vary from biotite to carbonate rich. The unit appears to grade into the iron formation and amphibolite.

Semipelitic to pelitic biotite gneiss

This variety of biotite gneiss forms layers up to 2 m wide that weather grey to brown and occur mostly between Burntwood Group gneiss and quartz-rich calcareous gneiss. Its mineral content includes quartz, biotite, clinopyroxene, ±magnetite ±orthopyroxene.

Layered amphibolite–iron formation assemblage

The amphibolite–iron formation assemblage is a northeast-trending linear unit exposed in several locations in the map area: 1) at the south end of the area; 2) north along a small peninsula in Kawaweyak Lake; 3) northeast on an island in the centre of the lake; and 4) northeast along the shoreline of Notakikwaywin Lake. The layered amphibolite comprises

- well-layered, medium- to fine-grained amphibolite that was possibly derived from pillow basalt, and coarse- to medium-grained layered amphibolite of uncertain origin; and
- coarse-grained amphibolite derived from uniform and layered gabbro.

The assemblage also includes four variations of sulphide-facies iron formation and sulphidic gneiss:

- silicate-sulphide–facies iron formation to sulphidic gneiss
- calcsilicate-sulphide–facies iron formation to sulphidic calcsilicate
- semimassive sulphide
- sulphidic biotite gneiss

The assemblage appears to grade into the calcareous rock and quartz-rich biotite gneiss. It is in sharp contact with intrusive granodiorite and gabbro.

Well-layered amphibolite

The well-layered amphibolite, up to 20 m wide, is dark grey to brown and consists of alternating hornblende- and diopside-rich layers that range in width from 5 mm to 1.5 m (Figure GS-6-3d). It is composed of plagioclase, amphibole, orthopyroxene, pyrrhotite, secondary biotite and calcite±diopside. The well-layered amphibolite may contain boudinaged orthopyroxene-bearing amphibole-rich layers, up to 10 cm wide, with pure amphibole lenses. The orthopyroxene is equant and the hornblende is bladed

Table GS-6-1: Samarium-neodymium isotope data for semipelitic gneiss (sample 12-06-141-1), Kawaweyak Lake.(1)

Sm (ppm)	Nd (ppm)	^{147}Sm/^{144}Nd	^{143}Nd/^{144}Nd	Uncertainty (±2σ)	T_{CR}(2)	ε_{Nd}^{T}(3)	^{145}Nd/^{144}Nd	UTM(4)	
								Easting	Northing
3.85	17.34	0.1343	0.51204	0.00001	2.15	3.6	0.34840	509562	6193724

(1) Analysis performed at the Radiogenic Isotope Facility, University of Alberta, Edmonton

(2) Nd model ages of crustal residence (T_{CR}) calculated according to the model of Goldstein et al. (1984) for samples with ^{147}Sm/^{144}Nd < 0.14.

(3) ε_{Nd}^{T} calculated for the time (T) 1.9 Ga

(4) Zone 14 (Nad 83)

(Figure GS-6-3e, f). Locally, eroded pockets of probable metacarbonate lenses are exposed in the unit.

The amphibolite occurs in a 100 m wide belt that includes >50% interlayered granodiorite on the large island in Kawaweyak Lake. It is thinly sandwiched between the biotite gneiss and the calcareous rock along the south shore of the lake, where it also repeats within the iron formation–amphibolite assemblage to the east. The gabbro and granodiorite are in sharp intrusive contact with the layered amphibolite.

Coarse- to medium-grained amphibolite, gabbro

A coarse- to medium-grained dark grey amphibolite is interpreted to be derived from gabbro. It generally forms massive and uniform sheet-like bodies up to 4 m wide but is locally layered (Figure GS-6-4a). It intrudes the layered amphibolite–iron formation assemblage with sharp contact relationships, some of which are marked by fine-grained chilled margins. In several places, the gabbro occurs between granodiorite and the layered amphibolite, or within layers of silicate-sulphide–facies iron formation. The close spatial association with the layered amphibolite suggests that parts of these units may be comagmatic. The gabbro is intruded by pegmatite.

The gabbro is composed of hornblende, plagioclase and minor pyrrhotite. Internal layering is defined by varying proportions of plagioclase and is interpreted as primary crystal layering. Plagioclase up to 1 cm locally rims crystals of orthopyroxene (Figure GS-6-4b).

Iron formation to sulphidic gneiss

Various facies of interleaved rusty, green and grey-brown iron formation occur within the layered amphibolite–iron formation assemblage. Each facies exhibits gradational changes in mineral content and ranges from 0.3 to 7 m in width.

Sulphide-facies iron formation

The unit of sulphide-facies iron formation, about 1 m wide, is composed of quartz, pyrite, massive pyrrhotite and local bornite. It forms a layer adjacent to calcsilicate-sulphide, sulphide-bearing biotite-gneiss and the layered amphibolite. Lenses of sulphide-facies iron formation are present as inclusions in granodiorite.

Silicate-sulphide–facies iron formation

The unit of silicate-sulphide–facies iron formation varies from 0.3 to 7 m wide and includes sulphidic gneiss or 'lean iron formation'. It includes orthopyroxene, clinopyroxene and pyrrhotite. This unit generally occurs on the northwest side of the amphibolite–iron formation assemblage, with the sulphide facies to the southwest. It is in contact with Burntwood Group gneiss and intruded by granodiorite and gabbro (Figure GS-6-3f).

Calcsilicate-sulphide–facies iron formation

A unit of interlayered calcsilicate- and sulphide-facies iron formation is up to 5 m wide, with sulphidic calcsilicate gneiss included. It occurs in the south-central part of the lake between calcareous biotite gneiss and the true sulphide-facies iron formation. Its mineral content varies from carbonate rich near the calcareous rock to pyrrhotite rich toward the sulphide-facies layer in the amphibolite assemblage.

Sulphidic biotite gneiss

The biotite gneiss within the amphibolite–iron formation assemblage occurs in local brown-weathering interlayers that can be up to 2 m wide but are generally about 10 cm. The unit is generally schistose and can be very fine grained. Its mineral content includes pyrrhotite and rarely bornite.

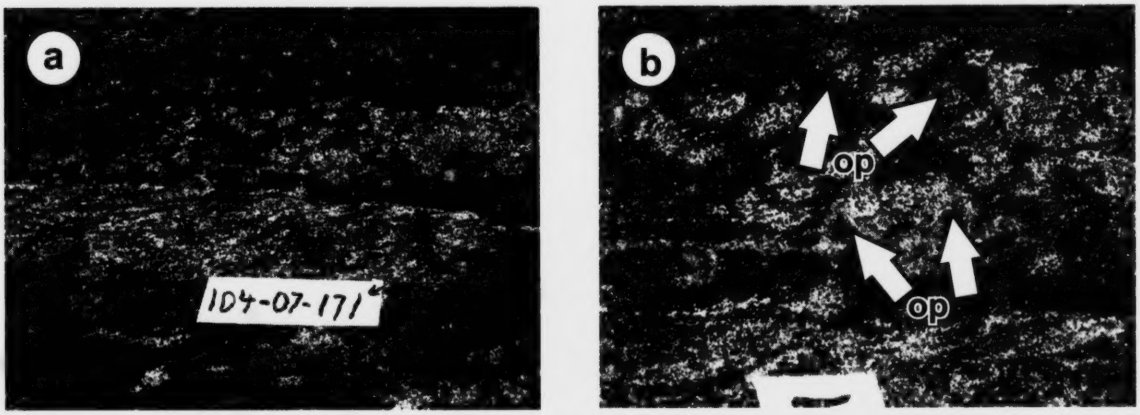

***Figure GS-6-4**: Gabbro at the north end of the Kawaweyak Lake area: **a)** gabbro showing primary crystal layering in plagioclase concentrations; plagioclase-rich lenses up to 1 cm in width (above tape) may be part of leucogabbro layers; **b)** close-up of same gabbro, showing a core of orthopyroxene rimmed by plagioclase (arrows). White tape for scale is 9–10 cm long and 2.5 cm wide.*

Granitoid intrusive rocks

Burntwood Group gneiss and the amphibolite–iron formation assemblage in the Kawaweyak Lakes area are intruded by granodiorite, granite and pegmatite, which are described below.

Granodiorite

The granodiorite weathers cream to grey-brown and is foliated to massive. It is generally equigranular, the grain size ranging from medium to coarse. It is synmetamorphic and contains the regional metamorphic assemblage of garnet, biotite, sillimanite and cordierite. In places, the granodiorite contains inclusions of Burntwood Group gneiss, amphibolite, silicate-sulphide–facies iron formation and rusty lenses up to 3 cm wide. The granodiorite is composed of quartz, feldspar, hornblende, biotite, cordierite, sillimanite and garnet. The unit intrudes the Burntwood Group, the quartz-rich to calcareous gneiss and the amphibolite–iron formation assemblage. In each location, the mineral content of the granodiorite close to the contact displays contamination by the adjacent country rock, expressed as 1) garnet and biotite adjacent to Burntwood Group gneiss; and 2) hornblende, diopside, magnetite and pyrrhotite adjacent to amphibolite. The granodiorite is injected by younger pegmatite and finer grained granitic veins.

Granite and pegmatite

The granite is white to grey, relatively coarse grained and, in places, contains garnet and cordierite. The unit also forms veins and finer grained dikes with a pegmatitic margin phase intruding the Burntwood Group gneiss. The granite locally contains up to 50% pink pegmatite.

Pegmatite is located in all of the rock units and may constitute up to 80% of the outcrop, especially along the west shoreline of Kawaweyak Lake.

Discussion and economic considerations

Rocks similar to the amphibolite–iron formation assemblage overlying the Burntwood Group occur elsewhere in the Kisseynew Domain (Zwanzig, 1990). They are preserved as pillow basalt (Tod Lake basalt), gabbro and sulphide-facies iron formation associated with siliciclastic sedimentary rocks and calcsilicate rocks in the Granville Lake structural zone (GSZ in Figure GS-6-1) at Granville Lake and the southwest end of the Lynn Lake belt (Zwanzig et al., 1999). That succession has been interpreted as part of a crustal suture extending from an area north of the TNB west into Saskatchewan (White et al., 2000). The rocks are part of the juvenile Paleoproterozoic internal zone of the Trans-Hudson Orogen and unrelated to the TNB.

The Paleoproterozoic Nd model age of 2.15 Ga from the semipelitic gneiss in the study area further supports an origin in the Trans-Hudson internal zone. A sample from quartz-rich calcareous biotite gneiss (calcsilicate) from Wuskwatim Lake yielded a Nd model age of 2.4 Ga, also juvenile Paleoproterozoic (Zwanzig et al., 2006). The latter unit was considered part of the Burntwood Group, an alternate interpretation that is also possible for Kawaweyak Lake because sulphide-facies iron formation is clearly interlayered with the Burntwood Group at Notigi Lake (Murphy and Zwanzig, GS-5, this volume).

The various possible associations of the amphibolite–iron formation assemblage indicate that the tectonostratigraphy of the northeastern Kisseynew Domain is complex and thorough ground-truthing is therefore required before maps can be redrawn based on new aeromagnetic data.

Regardless of its exact origin, the amphibolite–iron formation assemblage is best interpreted as unrelated to similar-looking rocks in the TNB and the adjacent Wuskwatim corridor because these rocks include more pelitic gneiss, yield Archean Nd model ages and are more clearly in fault contact with the Burntwood Group (Zwanzig et al., 2006). If the assemblage at Kawaweyak Lake is equivalent to the assemblage at Granville Lake, it may have economic potential for gold rather than for nickel, since showings containing trace gold occur in similar amphibolite with a sulphidic layer directly south of Granville Lake.

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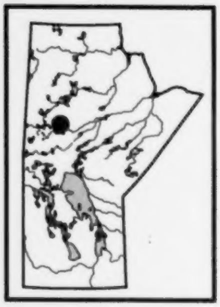
GS-7

New field and geochronological results for the Osik–Atik–Footprint lakes area, Manitoba (NTS 63O13, 14, 15, 64B2, 3)

by J.A. Percival[1], N. Rayner[1], M.L. Growdon[2], J.B. Whalen[1] and H.V. Zwanzig

Percival, J.A., Rayner, N., Growdon, M.L., Whalen, J.B. and Zwanzig, H.V. 2007: New field and geochronological results for the Osik–Atik–Footprint lakes area, Manitoba (NTS 63O13, 14, 15, 64B2, 3); *in* Report of Activities 2007, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 71–81.



Summary

The oldest recognized units in the Osik–Atik–Footprint lakes are porphyritic granodiorite rocks identified by sensitive high-resolution ion microprobe (SHRIMP) U-Pb zircon ages on plutons at Atik Lake (1879 ±13 Ma) and Footprint Lake (1882 ±10 Ma). A supracrustal sequence containing quartz-rich sandstone and silicate-facies iron formation that borders a similar pluton at Wapisu Lake may be unconformable and underlie Burntwood Group (<1850 Ma) migmatite rocks, which make up most of the northeastern Kisseynew Domain. At Osik Lake, a hook-shaped body of homogeneous biotite tonalite is enveloped by a sheath of enderbite–quartz diorite–gabbro in structural contact with the Burntwood migmatite. The tonalite contains at least one layered mafic-ultramafic body that may be the source of a nickel-in-till anomaly south of Osik Lake.

Structurally, the area is characterized by a set of upright, gently northeast-plunging F_3 folds that reoriented a prominent S_2 foliation developed in all rock types except late granite and pegmatite. The map pattern of an outlier of Sickle Group rocks north of Osik Lake may be the product of structural interference.

Introduction

Recent work in the northeastern Kisseynew Domain of the Trans-Hudson Orogen has suggested potential for Thompson-type nickel mineralization within a supracrustal sequence resembling the Ospwagan Group (Growdon et al., 2006; Percival et al., 2006; Rayner et al., 2006; Zwanzig et al., 2006a, b). In the Wuskwatim Lake–Burntwood River area, inliers of Archean orthogneiss (Rayner and Percival, GS-8, this volume) and an overlying quartz-rich sandstone–iron formation package suggest the widespread presence of Superior Province crust beneath migmatite rocks of the Burntwood Group in this region. Recently acquired high-resolution aeromagnetic images (e.g., Coyle and Kiss, 2006) allow the tracing of magnetic units farther west, into areas where isotopically contaminated granitoid rocks are exposed (Percival et al., 2005, 2006; Zwanzig et al., 2006a) and nickel anomalies are present in till (DiLabio and Kaszycki, 1988).

This report stems from the Flin Flon project of the Targeted Geoscience Initiatives Program, aimed at identifying new base-metal exploration targets in northern Manitoba and Saskatchewan. In conjunction with concurrent work by Murphy and Zwanzig (GS-6, this volume; GS-5, this volume), the paper describes the regional geology of the Footprint–Osik–Notigi lakes area, last mapped by Frohlinger and Kendrick (1979) and Kendrick et al. (1979). It includes significant modifications to the geology of the Osik Lake area. In particular, the recognition of plutonic rocks, including a layered mafic-ultramafic complex, rather than arkose of the Sickle Group, increases the nickel exploration potential of the area.

Regional geological setting

Traditionally, the boundary between the Archean Superior Province and the Paleoproterozoic Trans-Hudson Orogen is a north-northeast–trending, steeply dipping zone located a few kilometres west of Thompson (Figure GS-7-1; Zwanzig et al., 2003; Macek et al., 2006). Based on seismic reflection images, the boundary is interpreted to dip eastward (White et al., 2002). The Paleoproterozoic Ospwagan Group, lying unconformably on Superior Province basement (Bleeker, 1990), hosts mafic-ultramafic sills (ca. 1885 Ma; Hulbert et al., 2005) and their contained nickel deposits (Macek et al., 2006).

Recent work has shown extensions of the Superior Province, including Meso- to Paleoarchean gneiss (cf. Böhm et al., 2003) and associated Paleoproterozoic cover rocks northwest of the traditional Superior Boundary Zone (Zwanzig and Böhm, 2004). Inliers of similar material in structural culminations within the Kisseynew Domain extend the Superior basement another 50 km to the west (Percival et al., 2006; Zwanzig et al., 2006a, b; Rayner and Percival, GS-8, this volume). Metamorphic grade is uniformly high in the northeastern Kisseynew Domain, reaching granulite facies in some culminations (Growdon et al., 2006). Throughout the region, abundant pegmatite and granite of anatectic origin cut the Burntwood migmatite.

To the northwest of the basement orthogneiss culminations are several elongate bodies of K-feldspar–porphyritic granodiorite, surrounded by migmatitic

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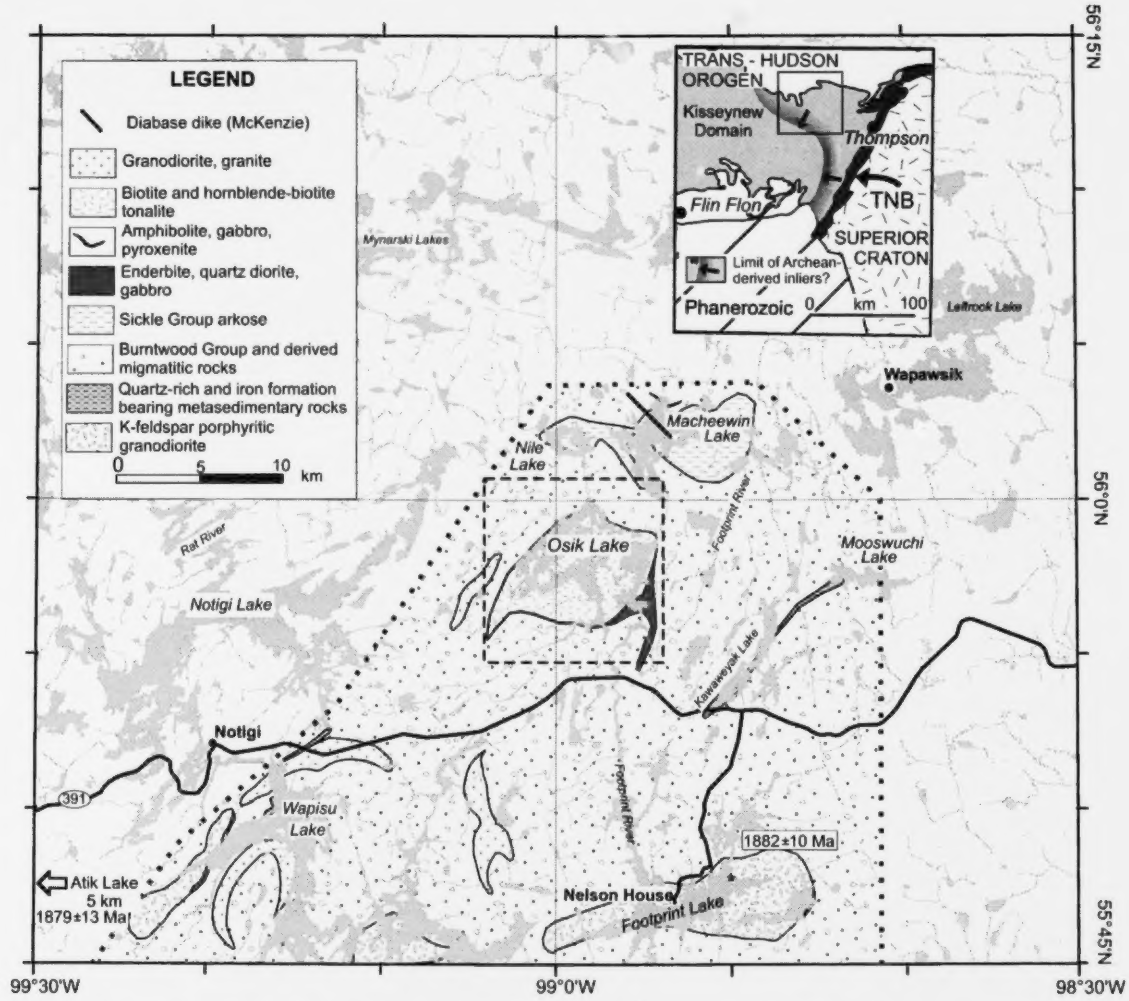

LEGEND
Diabase dike (McKenzie)
Granodiorite, granite
Biotite and hornblende-biotite tonalite
Amphibolite, gabbro, pyroxenite
Enderbite, quartz diorite, gabbro
Sickle Group arkose
Burntwood Group and derived migmatitic rocks
Quartz-rich and iron formation bearing metasedimentary rocks
K-feldspar porphyritic granodiorite
0 5 10 km
TRANS.- HUDSON OROGEN
Kisseynew Domain
Thompson
Flin Flon
TNB
SUPERIOR CRATON
Limit of Archean-derived inliers?
Phanerozoic
0 km 100
Mynarski Lakes
Leftrook Lake
Wapawsik
Macheewin Lake
Nile Lake
Osik Lake
Footprint River
Mooswuchi Lake
Rat River
Notigi Lake
Kawaweyak Lake
Notigi
391
Wapisu Lake
Footprint River
1882±10 Ma
Atik Lake 5 km
1879±13 Ma
Nelson House
Footprint Lake
56°15'N
56°0'N
55°45'N
99°30'W
99°0'W
98°30'W

***Figure GS-7-1:** Generalized geological map of the Osik–Atik–Footprint lakes area showing the distribution of major rock units, the location of geochronological sites and place names referred to in the text (modified after Baldwin et al., 1979). Inset map shows the location of the study area with respect to regional tectonic features. The box outlined with the dashed line shows the location of Figure GS-7-2.*

metasedimentary rocks (Kendrick et al., 1979; Frohlinger and Kendrick, 1979; Hollings and Ansdell, 2002). Bodies at Footprint and Atik lakes yielded ε_{Nd} values of –9.3 and –10.3 (at t = 1885 Ma), respectively, suggesting either an Archean age or contamination by Archean crust (Percival et al., 2006).

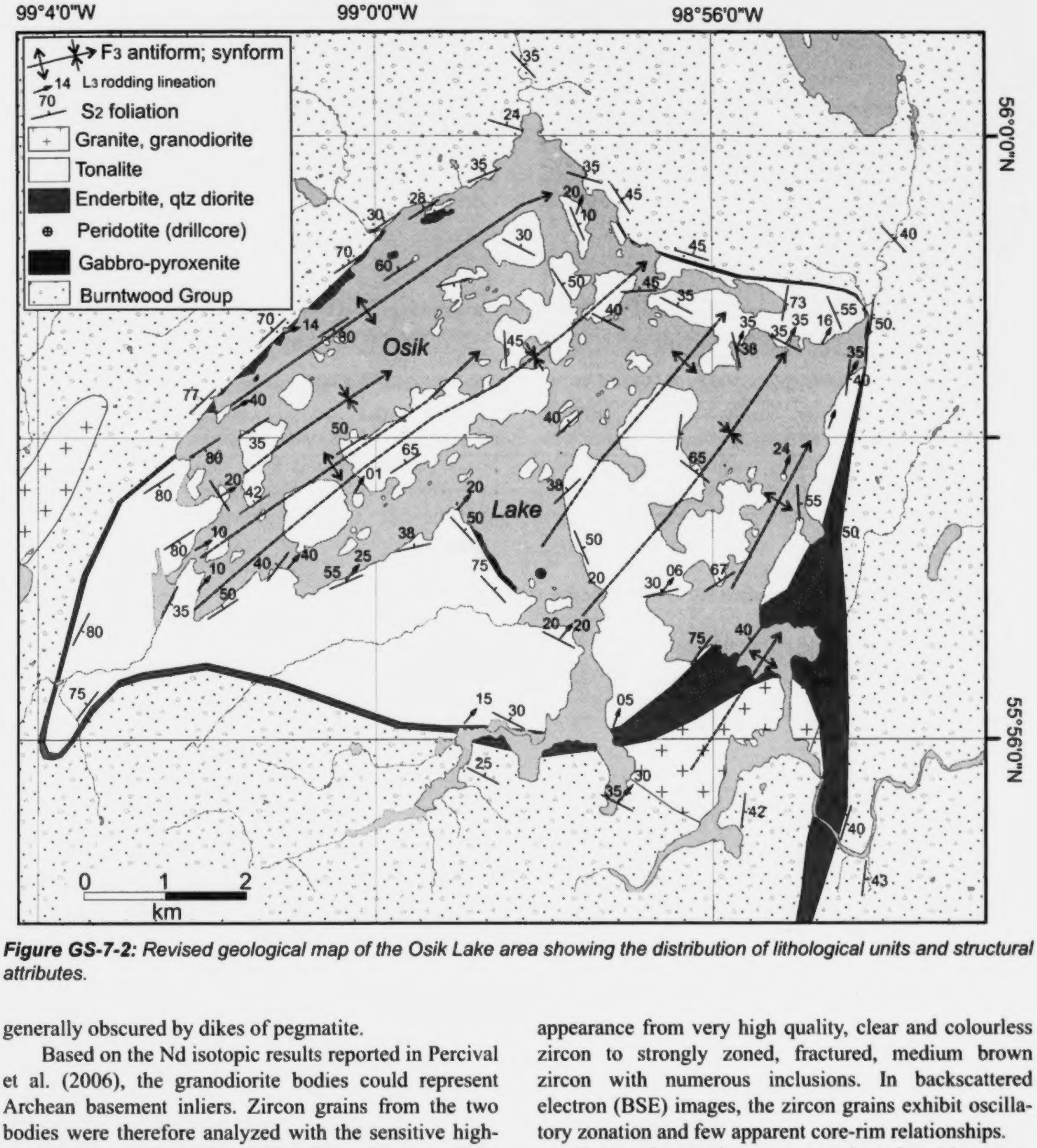
The Kisseynew Domain is bounded to the north by the Lynn Lake–Leaf Rapids Domain (Zwanzig, 1990; Ansdell, 2005; Corrigan et al., 2007). This major tectonic boundary (White et al., 2000) is marked by the Granville Lake structural zone (Zwanzig, 2000; Corrigan et al., 2007; Murphy and Zwanzig, GS-5, this volume).

Tectonostratigraphic units

Several units in addition to the dominant metasedimentary migmatite of the Burntwood Group were identified in the Osik–Atik–Footprint lakes area (Figures GS-7-1, -2).

K-feldspar porphyritic granodiorite

Four bodies of porphyritic granodiorite were examined at Footprint Lake, eastern and western Wapisu Lake, and Atik Lake. All are homogeneous, hornblende-biotite granodiorite with K-feldspar phenocrysts up to 4 cm (Figure GS-7-3a). They are commonly strongly foliated to augen gneiss and variably intruded by granitic and pegmatitic dikes. Mafic dikes up to 4 m wide (Figure GS-7-3b) occur within all of the plutons, and diffuse enclaves of diorite to gabbro are present in the Atik Lake body. Contacts with surrounding rocks are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99°0'0"W
98°56'0"W
56°0'0"N
55°56'0"N
F3 antiform; synform
L3 rodding lineation
S2 foliation
Granite, granodiorite
Tonalite
Enderbite, qtz diorite
Peridotite (drillcore)
Gabbro-pyroxenite
Burntwood Group
Osik
Lake
0
1
2
km

Figure GS-7-2: Revised geological map of the Osik Lake area showing the distribution of lithological units and structural attributes.

generally obscured by dikes of pegmatite.

Based on the Nd isotopic results reported in Percival et al. (2006), the granodiorite bodies could represent Archean basement inliers. Zircon grains from the two bodies were therefore analyzed with the sensitive high-resolution ion microprobe (SHRIMP) to determine their crystallization ages. A brief description of the analytical method is found in Rayner and Percival (GS-8, this volume) and details of the instrument settings are given in the footnotes to DRI2007003[1].

Zircon grains recovered from the Atik Lake granodiorite (25-71-328; lab #8957) are generally prismatic with slightly resorbed facets. In transmitted light, they range in appearance from very high quality, clear and colourless zircon to strongly zoned, fractured, medium brown zircon with numerous inclusions. In backscattered electron (BSE) images, the zircon grains exhibit oscillatory zonation and few apparent core-rim relationships.

Twenty-four analyses were conducted on 14 separate zircon grains, targeting the entire spectrum of morphologies and internal structures. Uranium concentrations are low, ranging from 30 to 100 ppm, and most have distinct Th/U ratios of greater than 1. The weighted mean ^{207}Pb/^{206}Pb age of all but one of the analyses yields an age of 1879 ±13 Ma (2σ), which is interpreted as the crystallization age (Figure GS-7-4). The analysis with the youngest

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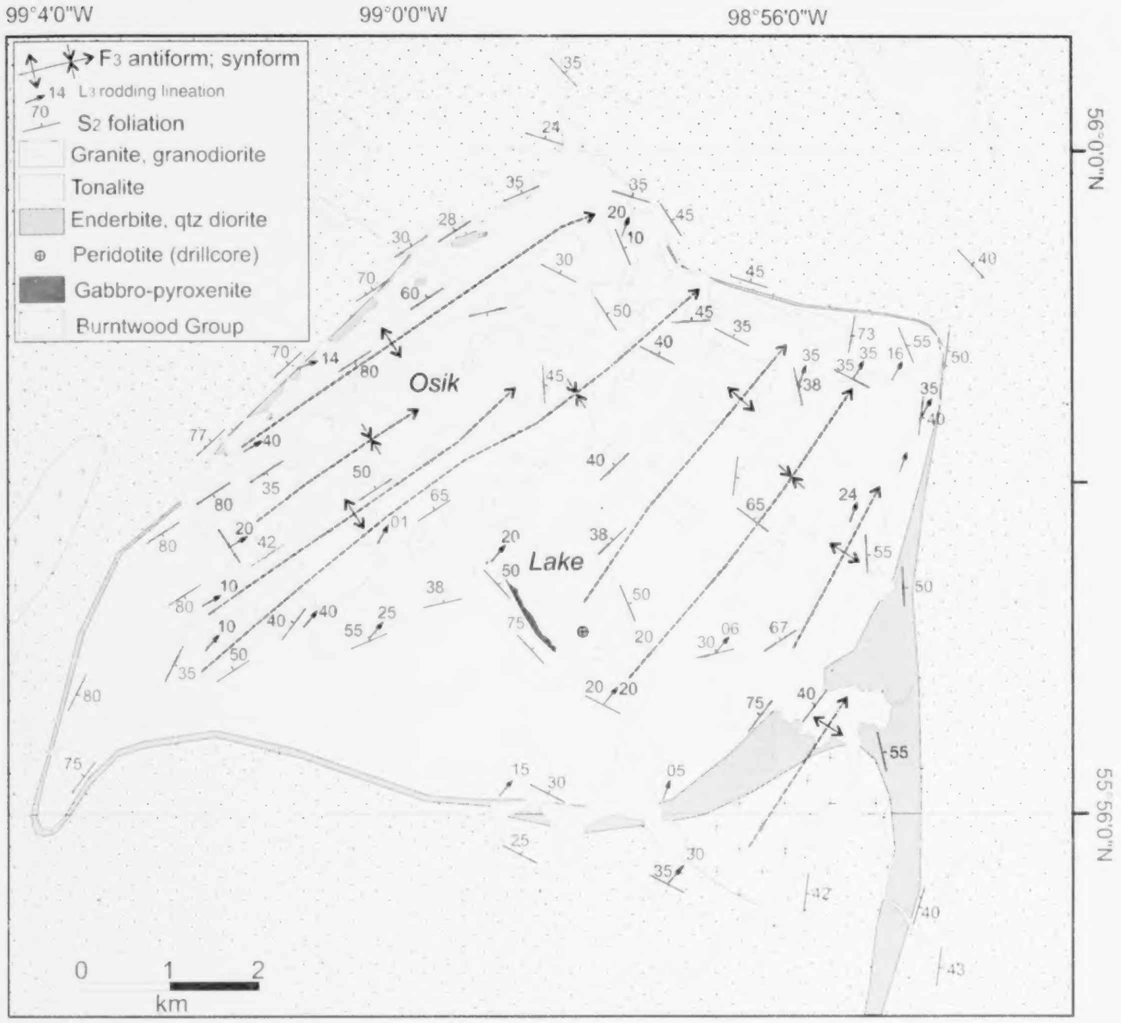
[1] MGS Data Repository Item DRI2007003, containing the data or other information sources used to compile this report is available online to download free of charge at http:///www2.gov.mb.ca/itm-cat/freedownloads.htm, or on request from minesinfo@gov.mb.ca or Mineral Resources Library, Manitoba Science Technology, Energy and Mines, 360–1395 Ellice Avenue, Winnipeg, MB R3G 3P2, Canada


99°4'0"W
99°0'0"W
98°56'0"W
56°0'0"N
55°56'0"N
F3 antiform; synform
14 L3 rodding lineation
70 S2 foliation
Granite, granodiorite
Tonalite
Enderbite, qtz diorite
Peridotite (drillcore)
Gabbro-pyroxenite
Burntwood Group
Osik
Lake
0
1
2
km

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[1] MGS Data Repository Item DRI2007003, containing the data or other information sources used to compile this report is available online to download free of charge at http://www2.gov.mb.ca/itm-cat/freedownloads.htm, or on request from minesinfo@gov.mb.ca or Mineral Resources Library, Manitoba Science Technology, Energy and Mines, 360–1395 Ellice Avenue, Winnipeg, MB R3G 3P2, Canada

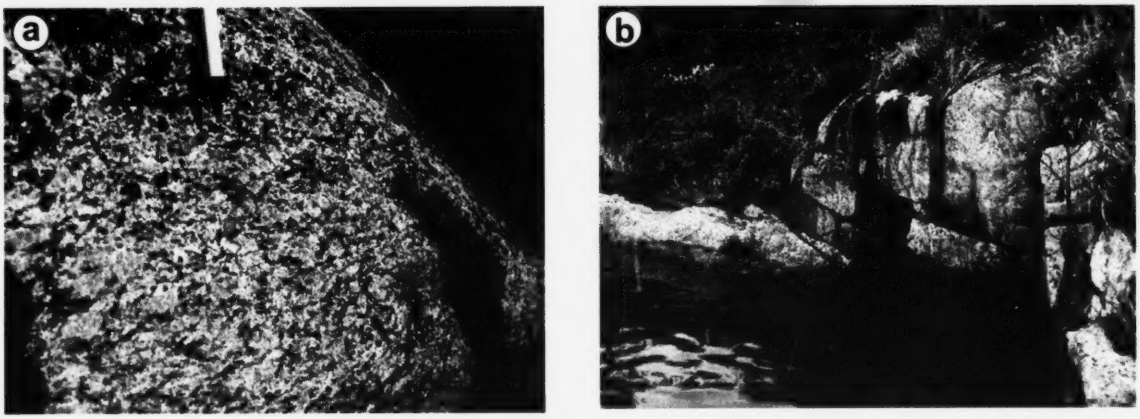

Figure GS-7-3: *Porphyritic granodiorite:* ***a)*** *foliated homogeneous granodiorite, Wapisu east pluton; pen for scale;* ***b)*** *foliated granodiorite cut by a 25 cm thick foliated mafic dike.*

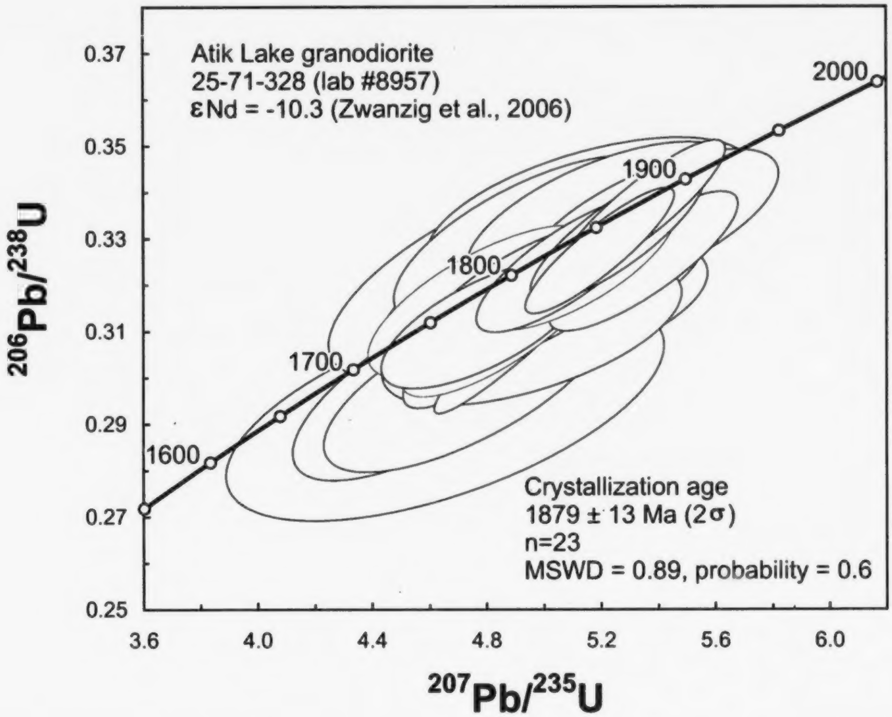

Figure GS-7-4: *Concordia diagram with U-Pb sensitive high-resolution ion microprobe (SHRIMP) data from the Atik Lake granodiorite. The rock has a whole-rock* ε_{Nd} *value (t = 1885 Ma) of –10.3, suggesting contamination by crust of Archean age.*

date (8957–97.1) was excluded on the basis of its distinct Th/U ratio of 0.08, but it is statistically indistinguishable from the rest of the analyses. Due to the low U concentrations, the errors for individual analyses are quite large. To determine if any of the observed scatter is distinct from the analytical uncertainty, four or five replicate analyses were conducted on the apparent youngest, oldest and intermediate-aged zircon. The within-grain scatter is comparable to the scatter observed in the entire population and therefore suggests that these zircon grains form a single statistical population.

The Footprint Lake granodiorite (25-71-412; lab #8955) yielded abundant, slightly resorbed, prismatic zircon that exhibited strong oscillatory zoning in BSE images. The zircon grains are variably fractured and altered and many contain large inclusions. A range of morphologies was targeted for SHRIMP analysis.

Twenty-four analyses were carried out on 15 separate zircon grains. As with the previous sample, U concentrations were low to moderate (20–250 ppm) and Th/U ratios typically greater than 1; values were up to 2.7. Replicate analyses were conducted on three grains. Again, the intra-zircon variability reflected the scatter in the entire dataset, allowing the dataset to be interpreted as a single statistical population. The weighted mean ^{207}Pb/^{206}Pb age of all analyses is 1882 ±10 Ma (2σ), which is interpreted as the crystallization age (Figure GS-7-5).

No inherited Archean cores were observed in either of the samples despite the strongly negative ε_{Nd} results (Percival et al., 2006). The new ages resemble that of the Clarke Lake granodiorite, a porphyritic granodiorite pluton intruding into Superior Province basement near Wabowden (1885 ±5 Ma; Percival et al., 2005). Furthermore, zircon grains from all three granodiorite bodies have distinctive Th/U values, typically greater than 1 and up to 2.7. In light of the isotopic contamination and age, the authors conclude that the Footprint and Atik plutons, and by inference, the Wapisu east and west bodies, represent part of a basement complex that includes 1880–1885 Ma plutons. Forthcoming geochronology will confirm the age of the Wapisu west body.

Sedimentary cover sequence

In a few locations, contacts between plutons of porphyritic granodiorite and surrounding rocks are relatively well preserved. In southwestern Wapisu Lake, a north-trending, vertically dipping panel of metasedimentary rocks of diverse composition may represent an unconformable sequence. The section is variably intruded by pegmatite sheets up to 5 m thick. Immediately east of the granodiorite is a 1 m thick section of massive to thick-bedded, gritty quartz arenite and fine-grained, thinly layered quartz-rich sandstone (Figure GS-7-6a, b). Sparse enclaves and rafts in pegmatite over the succeeding 15 m are biotite-rich schist with rare garnet. A well-preserved 20 m section to the east consists of biotite-rich schist and silicate- and sulphide-facies iron formation, interlayered on a 50–100 cm scale. Also present are 20–100 cm thick layers of amphibolite, sulphidic garnet-biotite schist and fine-grained, quartz-rich rocks whose protolith may be chert. Approximately half of this section is made up of sheets of granitic pegmatite. The eastern end of the section is dominantly pegmatite, containing screens and rafts of medium-grained biotite-garnet granite. To the east, pegmatite contains screens and rafts of migmatitic garnet-biotite paragneiss, resembling rocks of the Burntwood Group.

Iron formation is present elsewhere within metasedimentary rocks to the northeast, in the Osik–Kawaweyak–Mooswuchi lakes area. This is an atypical association for the Burntwood Group, which elsewhere consists of metagreywacke and derived migmatite (Baldwin et al.,

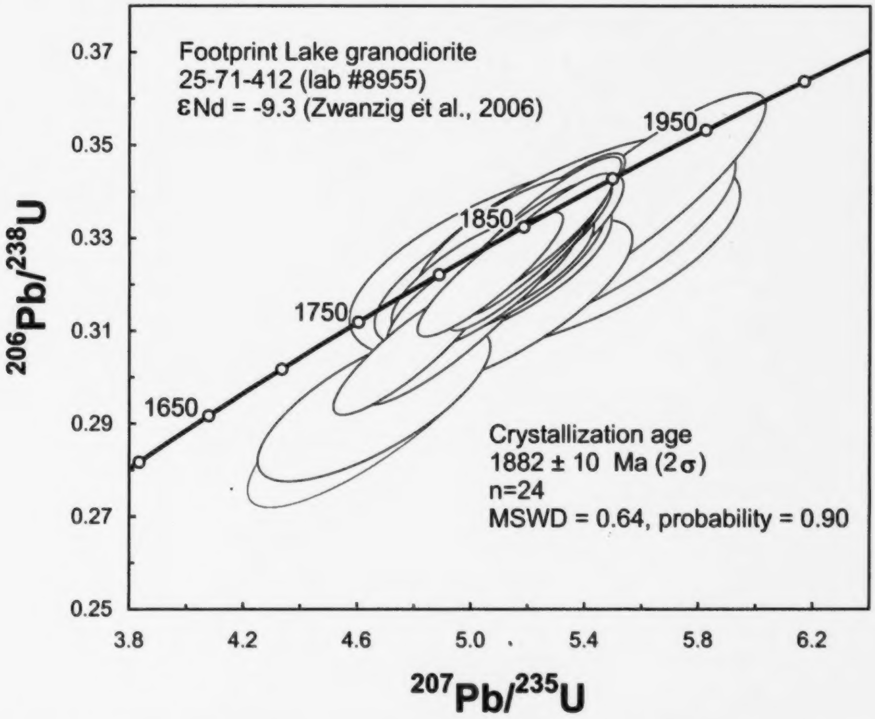

Figure GS-7-5: *Concordia diagram with U-Pb sensitive high-resolution ion microprobe (SHRIMP) data from the Footprint Lake pluton. The rock has a whole-rock ε_{Nd} value (t = 1885 Ma) of –9.3, suggesting contamination by crust of Archean age.*

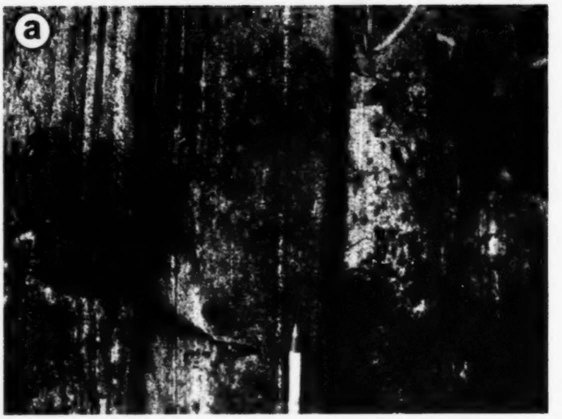

Figure GS-7-6: *Field photographs of metasedimentary units:* ***a)*** *quartz-rich sandstone above possible unconformable contact with the Wapisu west granodiorite pluton (to right of photograph); pen for scale;* ***b)*** *folds in thinly layered quartz-biotite sandstone, western Wapisu Lake; hammer for scale.*

1979; Murphy and Zwanzig, GS-6, this volume). The extent and distribution of the iron-rich units will be clarified by forthcoming high-resolution aeromagnetic maps.

Work is underway to date detrital zircon grains from quartz-rich rocks of the sedimentary section. The results will determine whether a pre-Burntwood sedimentary succession is present, as well as constrain the age of the source terrane. Based on field relationships, the assemblage could be of a similar age to the Duck Lake or Levesque Bay assemblages in Saskatchewan (Maxeiner et al., 2005), or possible correlatives in the Granville structural zone (Murphy and Zwanzig, GS-5, this volume) in Manitoba, although results to date would suggest Superior Province affinity (Percival et al., 2006).

Burntwood Group

The Burntwood Group and derived anatectic granitic rocks makes up most of the Kisseynew Domain (Zwanzig, 1990). In the present area, Burntwood rocks are garnet–biotite±cordierite±sillimanite migmatite rocks with up to 30% white granitic leucosome. Coarse cordierite is locally abundant in leucosome. With the exception of rare pelite-psammite couplets, primary features are not preserved. Metamorphic grade ranges from upper-amphibolite facies, defined by the assemblage garnet–cordierite–inferred melt, to granulite facies, indicated by the presence of orthopyroxene (cf. Growdon et al., 2006).

In northern Macheewin Lake (Figure GS-7-1), a mafic-ultramafic sill about 20 m thick was traced over a 1.2 km strike length within the Burntwood migmatite. The mafic rocks range from medium-grained, homogeneous amphibolite to layered, migmatitic, rusty amphibolite with ortho- and clinopyroxene. Massive to layered ultramafic rocks were observed at one location (UTM Zone 14, 506097E, 6212130N, NAD83). The coarse-grained pyroxenite contains up to 15% olivine in some metre-scale layers.

At Nile Lake (Figure GS-7-1), a 30 m thick sulphide-rich zone was traced over 1.5 km of strike length. It consists mainly of rusty garnet-biotite schist with up to 20% disseminated sulphide minerals, mainly pyrrhotite and pyrite. Layers of fine-grained, layered amphibolite up to several metres thick contain some carbonate and could be calcsilicate. Gabbroic layers up to 1 m thick contain some sulphide-rich zones. A 50 cm thick layer of rusty, muscovite-rich schist of possible tuffaceous origin occurs within a section of layered amphibolite and sulphidic chert.

Sickle Group

Units of the Sickle Group occur in the Nile and Macheewin lakes area (Figure GS-7-1). At Nile Lake, thinly bedded hornblende arkose and biotite±sillimanite arkose occur in a structural basin surrounded by the Burntwood migmatite (Figure GS-7-1). At Macheewin Lake, a map-scale unit of Sickle arkose has irregular geometry. Amphibolite is present at the Burntwood–Sickle interface at one location, whereas the contact appears conformable at another, where a 10 cm bed of thinly bedded quartz-rich sandstone characterizes the interface. In the same vicinity, layers of migmatitic garnet-biotite paragneiss resembling the Burntwood paragneiss occur within a sequence dominantly made up of thinly bedded biotite arkose.

Osik Lake plutonic units

Several plutonic units in the Osik Lake area correspond directly with rocks previously thought to be Sickle arkose (Frohlinger and Kendrick, 1979). Enderbite-suite rocks are dominantly medium-grained, homogeneous, hornblende–biotite±orthopyroxene±clinopyroxene quartz diorite. The suite contains metre-scale layers of diorite and gabbro with similar assemblages. The intensity of foliation varies inversely with the thickness of the body.

At the map scale, the body varies in thickness from 20 to 1000 m and forms a rim separating the Burntwood paragneiss on the outside from the Osik Lake tonalite pluton on the inside (Figures GS-7-1, -2). Sulphide-rich dioritic layers up to 50 cm thick are present in western Osik Lake (Figure GS-7-7).

Tonalitic rocks underlie most of Osik Lake. The main phase is a medium-grained, homogeneous, moderately foliated biotite tonalite containing 5–10% biotite and 20–30% quartz (Figure GS-7-8). It contains sparse enclaves of diorite and gabbro (Figure GS-7-9), including a distinctive 'snowflake-textured' metagabbro with poikilitic plagioclase phenocrysts up to 1 cm in diameter (Figure GS-7-10), as well as a layered mafic-ultramafic complex (*see* below). An older tonalitic phase with sparse orthopyroxene was noted locally. The penetrative foliation (S_2) in the main tonalitic phase has variable strike and dip that appear to be related by a set of northeast-trending F_3 folds (Figure GS-7-2).

At one location (UTM Zone 14, 501693E, 6200559N, NAD83), a layered gabbro-pyroxenite body at least 15 m thick and 100 m long is exposed on the lakeshore (Figure GS-7-11). Rhythmic centimetre-scale layers in gabbro give way to anorthositic gabbro, pegmatitic gabbro and pyroxenite. Abundant garnet is present in some layers. The body occurs in the vicinity of ultramafic cobbles noted by DiLabio and Kaszycki (1988), an aeromagnetic anomaly beneath the lake and about 100 m west of a drillhole that intersected peridotite containing 0.22% nickel (Figure GS-7-2; Canmine Resources Corporation, 1999). Work is underway to constrain the age of the body by dating zircon grains from a pegmatitic gabbro.

At least one younger phase of tonalite is present as sheets and dikes cutting the main phase tonalite. It is a homogeneous, medium-grained, hornblende-biotite

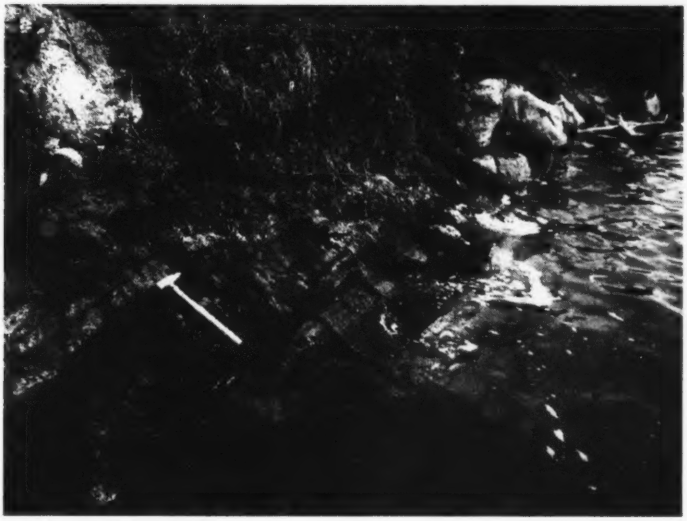

***Figure GS-7-7:** Sulphide-bearing layers in gabbro-diorite of the enderbite suite, western Osik Lake; hammer for scale.*

***Figure GS-7-8:** Homogeneous, medium-grained biotite tonalite, southeastern Osik Lake; pen tip for scale.*

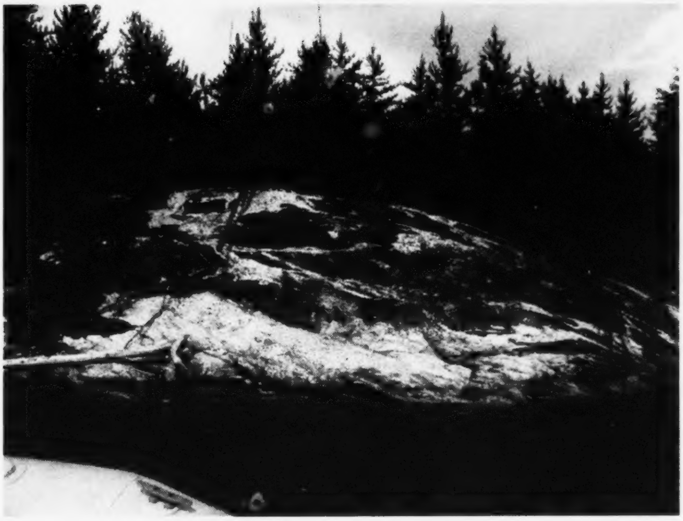

Figure GS-7-9: *Large gabbroic enclaves in tonalite, southwestern Osik Lake; width of photograph is 8 m.*

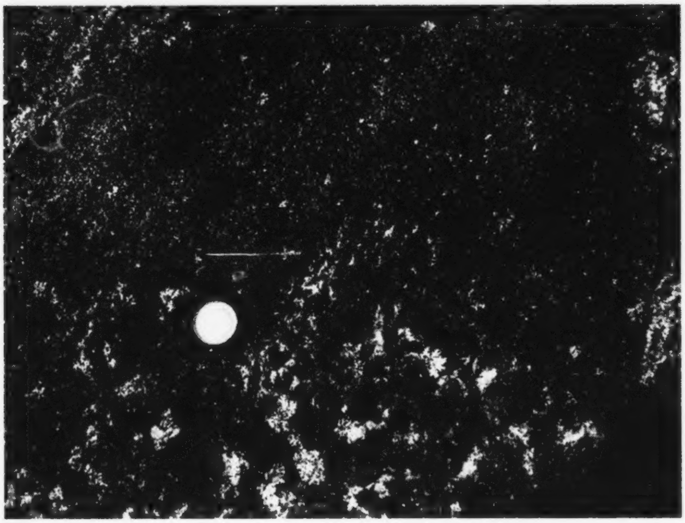

Figure GS-7-10: *Distinctive 'snowflake-textured' metagabbro, characteristic of metaplutonic enclaves within the Osik Lake tonalite; coin is 1.5 cm in diameter.*

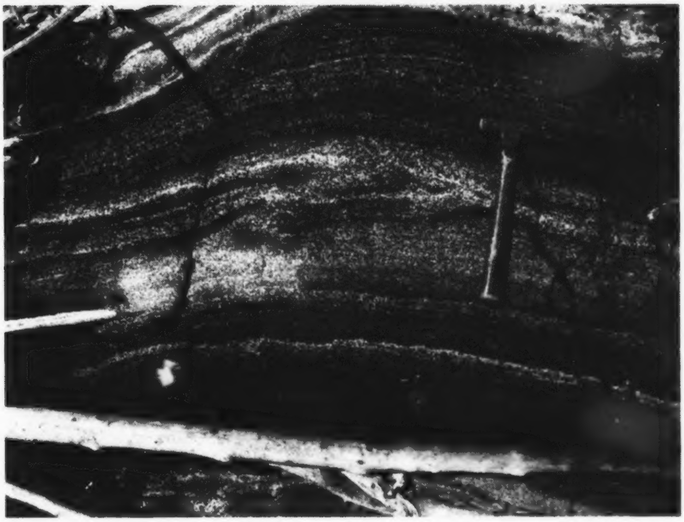

Figure GS-7-11: *Layered gabbro-pyroxenite showing the range of variation in the proportion of plagioclase and amphibole; hammer for scale.*

tonalite with a weak, northeast-striking foliation. These small bodies may be syntectonic with respect to the northeast-trending folds. Pods of younger granite to granodiorite have no foliation.

Structural geology

Polyphase regional deformation has been recognized throughout the Kisseynew Domain (Zwanzig, 1990), and Percival et al. (2006) reported evidence for at least four structural events in the northeastern Kisseynew Domain. Evidence of D_1 structures is sparse regionally and was not observed in the present area.

The most prominent structural element in the present area is a penetrative S_2 gneissosity developed in all rock types except late pegmatite and granite. In the Burntwood paragneiss, S_2 is a migmatitic layering and foliation defined by biotite alignment. Granodiorite carries a strong S_2 alignment of mafic minerals and K-feldspar augen, accentuated by leucosome veins. Tonalite at Osik Lake has a modest S_2 foliation produced by biotite alignment, whereas the enclosing enderbite rim is generally more strongly foliated. The fabric is typically defined by the alignment of mafic minerals. In several locations, the contact between enderbite and the structurally overlying Burntwood paragneiss is a high-strain zone characterized by flaggy, straight-layered gneiss (Figure GS-7-12) with deformed garnet porphyroblasts (Figure GS-7-13). These relationships suggest late D_2 timing for the high-strain event.

Geometrically, the Osik Lake structure has a northeast-dipping, northeast-plunging hook shape. Contacts dip moderately to the northeast at the northeastern (35–55°) and southwestern (25–55°) margins, and moderately to steeply outwards on the southeastern and northwestern flanks. The tonalitic core of the structure is separated from the Burntwood paragneiss by an envelope

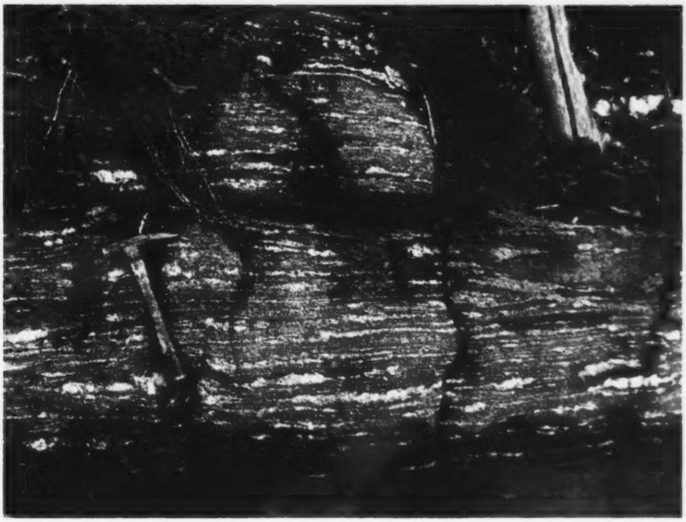

***Figure GS-7-12:** Straight gneiss developed from the Burntwood paragneiss, northern Osik Lake. Leucosome and pegmatitic veins are transposed parallel to the prominent foliation in this zone of strong deformation; hammer for scale.*

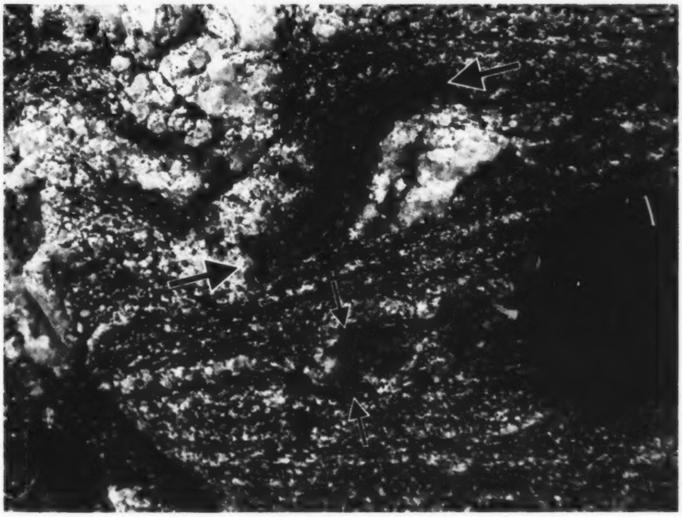

***Figure GS-7-13:** Close-up view of deformed garnet, southern Nile Lake. Curved shapes (identified by large arrows) and pressure shadows (example shown by small arrows) indicate strong deformation subsequent to the metamorphic peak; penny for scale.*

of enderbitic rocks, and virtually all enclaves in tonalite are derived from igneous rocks. In addition, contacts between the Burntwood paragneiss and enderbite appear highly strained (late S_2), making it unlikely that the tonalite intruded the Burntwood migmatite directly. The origin, age and isotopic characteristics of the tonalite are under investigation to determine the tectonostratigraphic affinity of the body.

A set of upright, northeast-plunging F_3 folds forms map-scale structures (Figure GS-7-2). Gentle plunges suggest that S_2 structures consistently had low dips prior to reorientation in F_3 folds. The wavelength and amplitude of folds vary regionally from broad open structures in the south to tighter 'wrinkles' in the Osik Lake area. To the north, in the Macheewin–Nile lakes area, the distribution of the Sickle and Burntwood units may be the result of fold interference patterns (Figure GS-7-1).

At Notigi Lake, 20 km to the west, the Granville Lake structural zone is marked by an amphibolite unit at the complexly folded interface between the Burntwood and Sickle units (Murphy and Zwanzig, this volume, GS-5). This zone does not appear to be present in the Osik–Macheewin lakes area, where Burntwood–Sickle contacts were observed. The significance of the high-strain zone at the margin of the Osik Lake structure is unlikely to be related to the Granville Lake structural zone in light of its dissimilar tectonostratigraphic setting and late-metamorphic timing.

Economic considerations

Several parts of the area warrant further exploration. At Osik Lake, nickel geochemical anomalies in till (DiLabio and Kaszycki, 1988) are explained partly by the presence of peridotite beneath the lake, but coincident gold values remain enigmatic. Sulphide-bearing horizons observed within Burntwood rocks north of Osik Lake could be the gold source and may be imaged on forthcoming aeromagnetic maps. Also possible is hydrothermal sulphide mineralization associated with intrusions in the northern Kisseynew Domain reported by Mumin and Trott (2003). To the north, the layered mafic-ultramafic body exposed at Macheewin Lake could also have nickel potential.

The occurrence of pre-Burntwood intrusions as far west as Atik Lake suggests the possibility of a basement complex beneath the region. Although these rocks could potentially host Thompson-type deposits (Percival et al, 2006; Zwanzig et al., 2006a), the potential would be limited by depth except near exposed culminations. Conversely, the region could be prospective for diamonds, provided that Archean lithosphere is still present and that kimberlitic conduits exist.

Acknowledgments

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GS-8 Uranium-lead geochronology of basement units in the Wuskwatim–Tullibee lakes area, northeastern Kisseynew Domain, Manitoba (NTS 63O)

by N. Rayner[1] and J.A. Percival[1]

Rayner, N. and Percival, J.A. 2007: Uranium-lead geochronology of basement units in the Wuskwatim–Tullibee lakes area, northeastern Kisseynew Domain, Manitoba (NTS 63O); *in* Report of Activities 2007, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p.82–90.

Summary

This report presents U-Pb sensitive high-resolution ion microprobe (SHRIMP) geochronological results from four high-grade samples of proposed Archean inliers within the Kisseynew Domain. A sample of tonalite from the Burntwood River, near the mouth of the Muskoseu River, is interpreted to have crystallized between 2.8 and 2.9 Ga; it also contains inherited zircon up to 3.4 Ga in age. A third population of zircon from the tonalite indicates zircon growth between 2.5 and 2.55 Ga, speculatively associated with granulite-grade metamorphism. Immediately overlying the tonalite is quartzite, which is interpreted to be in unconformable contact with the tonalite basement. The detrital zircon with the youngest reproducible age is dated at 2.53 Ga, with other detritus yielding minimum dates as old as 3.32 Ga. Uranium-lead results from a charnockite within the Wuskwatim Lake inlier are interpreted to indicate crystallization between 2.64 and 2.66 Ga, with inheritance between 2.7 and 3.24 Ga. All three of these samples also record peak Trans-Hudson metamorphism with zircon growth at 1801 ±13 Ma (tonalite), 1806 ±5 Ma (quartzite) and 1804 ±29 Ma (charnockite). Zircons recovered from a tonalite gneiss near an iron formation west of Tullibee Lake does not preserve evidence of an Archean history. All but one zircon yielded a weighted mean age of 1809 ±3 Ma, identical (within error) to the Paleoproterozoic ages observed in the Archean samples. Only one zircon yielded a slightly older date of 1877 ±22 Ma.

Introduction

Recent work by the Manitoba Geological Survey (MGS) and the Geological Survey of Canada (GSC) as part of the Targeted Geoscience Initiative III (TGI-3) program has identified structural windows of Archean orthogneiss in what was previously mapped as part of a sea of Paleoproterozoic Burntwood metaturbidites. Subsequent aeromagnetic surveys have identified other positive anomalies consistent with those observed in the Archean basement inliers. Details on the rock types, structure and metamorphism have been described in earlier reports and are illustrated in Figure GS-8-1 (Growdon et al., 2006; Percival et al., 2006; Zwanzig et al., 2006). In summary, basement orthogneiss is exposed in the core of several structural culminations at Wuskwatim Lake and a few kilometres to the northwest on the Burntwood River. Samarium-Neodymium tracer isotopic work on a charnockite from Wuskwatim Lake yielded a model age of 3.1 Ga (Percival et al., 2006). On the Burntwood River, near the Muskoseu River, an unconformity is exposed between quartz-rich metasedimentary rocks and a foliated tonalite with a model age of 3.3 Ga (Zwanzig et al., 2006). Detrital zircon geochronology (SHRIMP) on an arkosic quartzite from the Burntwood River yielded a provenance profile dominated by 2.7 Ga detritus (Zwanzig et al., 2006). Based on certain similarities of rock types and detrital provenance (yet differences in geochemistry), it has been suggested that this sequence of supracrustal rocks may be correlative with the Ospwagan Group and the orthogneiss may be correlative with a westward extension of the Superior Province basement (Percival et al., 2006; Zwanzig et al., 2006).

This report presents new SHRIMP U-Pb results for the Wuskwatim charnockite, the Muskoseu tonalite and unconformably overlying quartzite, and a tonalite at Tullibee Lake.

Analytical methods

Procedures followed for SHRIMP zircon U-Pb analysis are those described by Stern (1997), with standards and U-Pb calibration methods from Stern and Amelin (2003). The internal features of the zircons (such as zoning, structures and alteration) were characterized with backscattered electrons (BSE) utilizing a Cambridge Instruments scanning electron microscope. Analyses were conducted using an ^{16}O primary beam. Details of the specific analytical and instrumental conditions and the U-Pb calibration error can be found in the footnotes of DRI2007002[2]. Offline data processing was accomplished using the SQUID program (Ludwig, 2001) and customized in-house software. Isoplot v. 2.49 (Ludwig, 2003) was used to generate concordia plots and calculate weighted means. All ages in the text and the ellipses

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[1] Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario K1A 0E8

[2] MGS Data Repository Item DRI 2007002, containing the data or other information sources used to compile this report, is available online to download free of charge at http://www2.gov.bc.ca/itm-cat/freedownloads.htm, or on request from minesinfo@gov.mb.ca or Mineral Resources Library, Manitoba Science, Technology, Energy and Mines, 360–1395 Ellice Avenue, Winnipeg, MB R3G 3P2, Canada.

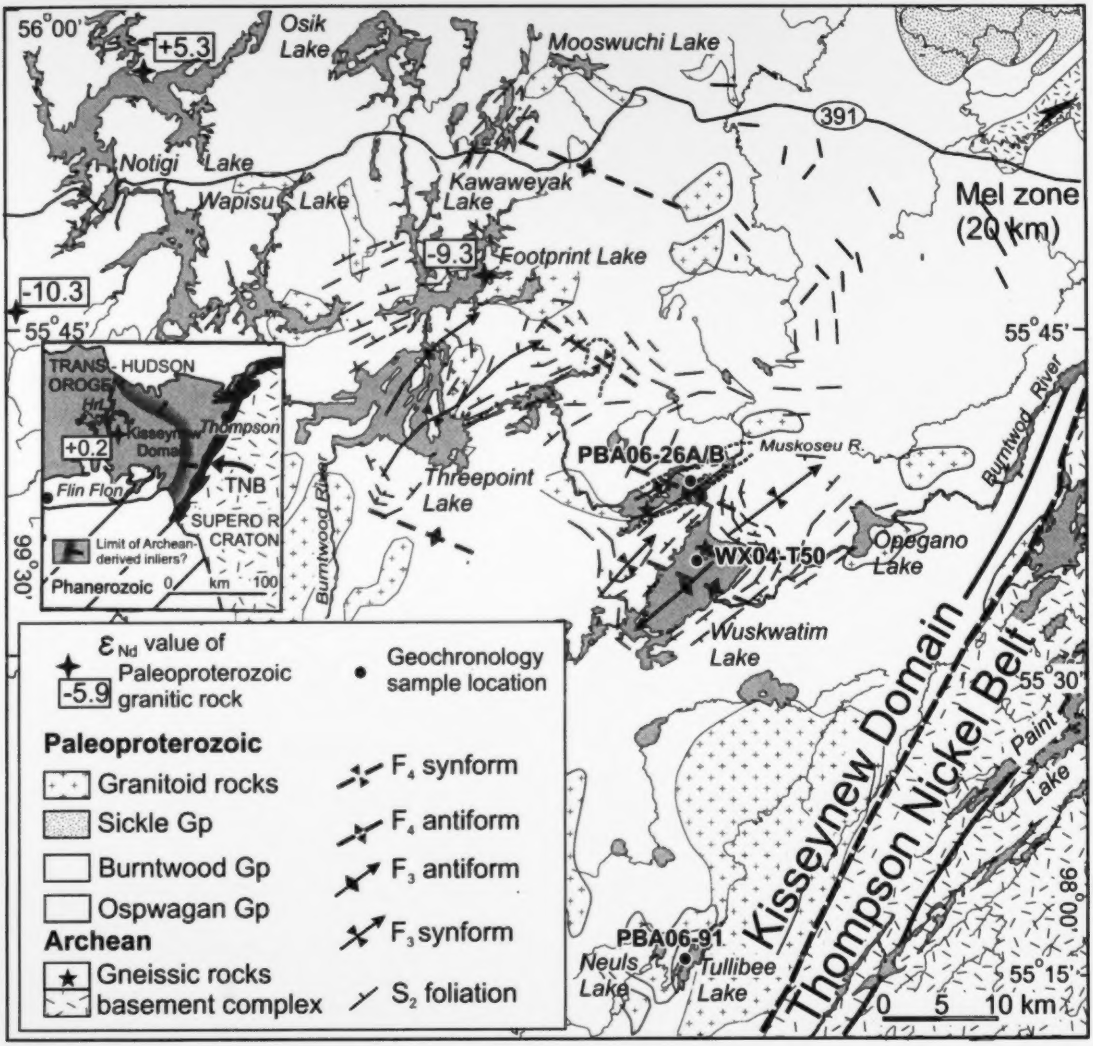

56°00'
+5.3
Osik Lake
Mooswuchi Lake
391
Notigi Lake
Wapisu Lake
Kawaweyak Lake
Mel zone (20 km)
-9.3
Footprint Lake
-10.3
55°45'
55°45'
TRANS-HUDSON OROGEN
Kisseynew Domain
Thompson
+0.2
Flin Flon
TNB
SUPERIOR CRATON
Limit of Archean-derived inliers?
Phanerozoic
0 km 100
99°30'
Burntwood River
Threepoint Lake
PBA06-26A/B
Muskoseu R.
Burntwood River
WX04-T50
Opegano Lake
Wuskwatim Lake
55°30'
Paint Lake
Kisseynew Domain
Thompson Nickel Belt
98°00'
PBA06-91
Neuls Lake
Tullibee Lake
55°15'
0 5 10 km
ε_{Nd} value of Paleoproterozoic granitic rock
-5.9
Geochronology sample location
Paleoproterozoic
Granitoid rocks
Sickle Gp
Burntwood Gp
Ospwagan Gp
Archean
Gneissic rocks basement complex
F4 synform
F4 antiform
F3 antiform
F3 synform
S2 foliation

Figure GS-8-1: Simplified geology of the Wuskwatim–Tullibee lakes area (from Percival et al., 2006).

plotted in the figures have errors reported at the 2σ uncertainty level.

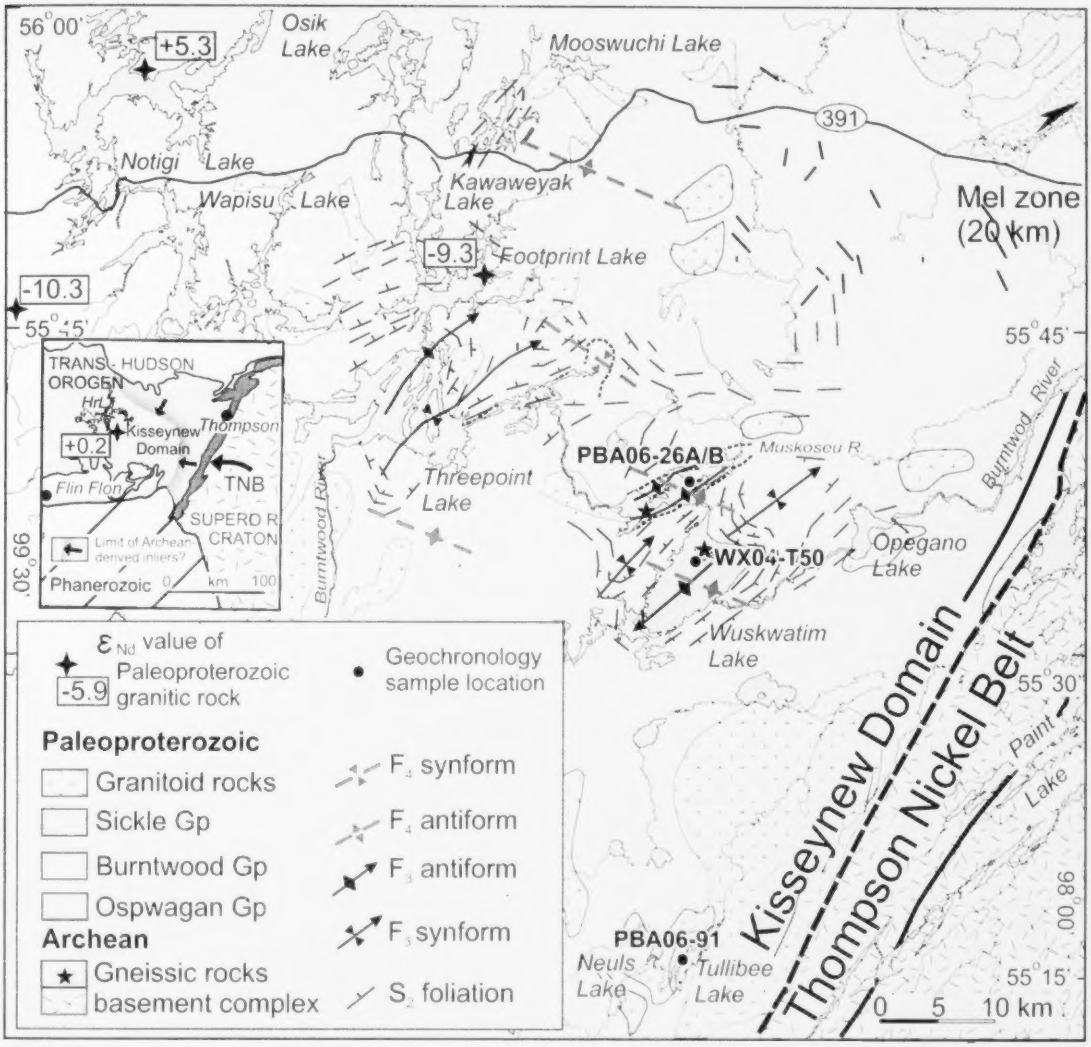
Sample details and results

Muskoseu tonalite (PBA06-26A)

At the locality near the Muskoseu River, a contact interpreted as an unconformity is exposed between the foliated tonalite and quartz-rich metasedimentary rocks (Figure GS-8-2a). The heterogeneous tonalitic unit comprises gneissic and foliated phases with orthopyroxene-clinopyroxene-hornblende-biotite-plagioclase-quartz assemblages. Sparse enclaves include garnet-orthopyroxene-biotite paragneiss and orthopyroxene-clinopyroxene-hornblende-plagioclase metabasite. Concordant leucosome and discordant leucogranite dikes are common.

Zircons recovered from the tonalite are highly variable in quality. They range from clear, colourless, high-quality prisms with few inclusions or fractures, to highly fractured and included prisms. The zircons show a weak cathodoluminescent response, but oscillatory zoning is visible in most grains. In a small number of grains, core-rim relationships are evident, in particular, clear rims surrounding poor-quality cores.

As has been observed in other high-grade rocks from the area, the U-Pb systematics of the older zircons are disturbed (Percival et al., 2005; Zwanzig et al., 2006). In a number of instances, replicate analyses on the same internal zone were not reproducible. Due to limited time constraints, it was not feasible to conduct replicate analyses on all the grains and therefore an unequivocal interpretation of any single age determination is not possible. By presenting and examining the data as concordia diagrams (Figure GS-8-3a) and probability


56°00'
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SUPERIOR CRATON
Limit of Archean-derived inliers?
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99°30'
Burntwood River
Threepoint Lake
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WX04-T50
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εNd value of Paleoproterozoic granitic rock
-5.9
Geochronology sample location
Paleoproterozoic
Granitoid rocks
Sickle Gp
Burntwood Gp
Ospwagan Gp
Archean
Gneissic rocks
basement complex
F4 synform
F4 antiform
F3 antiform
F3 synform
S2 foliation
55°30'
Kisseynew Domain
Thompson Nickel Belt
Paint Lake
98°00'
PBA06-91
Neuls Lake
Tullibee Lake
55°15'
0 5 10 km

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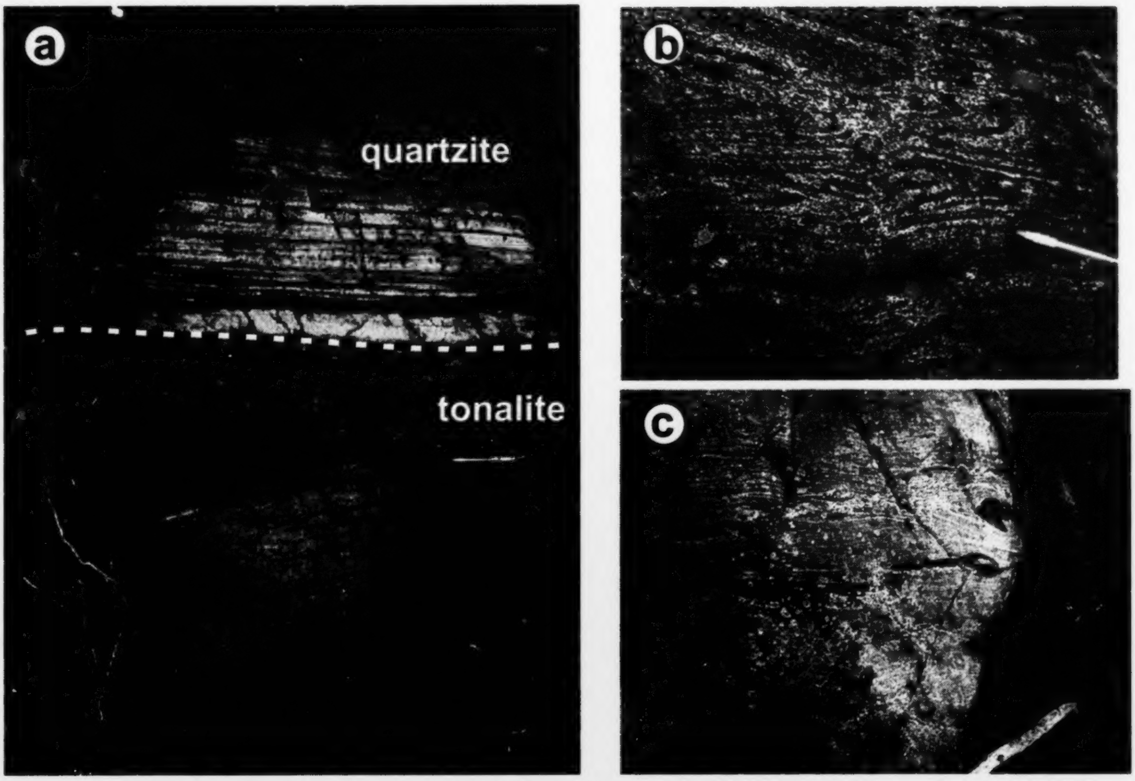


Figure GS-8-2: Photographs of rocks sampled for U-Pb geochronology: ***a)*** *Muskoseu River tonalite (PBA06-26A) and overlying quartzite (PBA06-26B); 16 cm pen for scale;* ***b)*** *detail of Tullibee tonalite gneiss (PBA06-91); 1 cm wide pen for scale;* ***c)*** *Tullibee tonalite gneiss (PBA06-91 with mafic enclaves); 16 cm pencil for scale.*

density diagrams with overlaid histograms (Figure GS-8-3b), the authors were best able to identify the prominent age modes and tentatively interpret these dates.

Beginning with the youngest results, three analyses of unzoned to faintly sector-zoned zircon give a mean age of 1801 ±13 Ma (2σ, mean square of weighted deviates (MSWD) = 0.61, probability of fit = 54%). This date is interpreted to represent the timing of Trans-Hudson metamorphism and is consistent with monazite results in the region (Growdon et al., 2006).

The remaining older zircons yielded ^{207}Pb/^{206}Pb ages ranging from 2392 to 3417 Ma. There is no clear relationship between zircon morphology and age. Replicate analyses of grains that at first yielded Paleoproterozoic or Neoarchean dates subsequently yielded older dates (e.g., grains 1, 5, 64, 68). The dominant age mode is between 2.8 and 2.9 Ga (Figure GS-8-3b). The authors interpret the crystallization age of the tonalite to be within this range, but cannot constrain it further due to the non-reproducibility of the results. The older age modes at ca. 2.95 and 3.4 Ga are interpreted as inherited components. The oldest ^{207}Pb/^{206}Pb date was determined from one of the poor-quality cores described earlier. Another prominent cluster of data is found in the range of 2.50–2.55 Ga, separated from the older population by an indistinct swath of results. A pronounced peak in the cumulative probability curve is shown at ca. 2.7 Ga (Figure GS-8-3b). This is based on a single, non-reproduced, precise analysis and does not necessarily indicate a geologically significant age. The authors would propose that the 2.5–2.55 Ga zircon growth and resetting of older zircons occurred due to granulite-grade metamorphism at this time or slightly later. The 1.8 Ga zircons described earlier are not affected by the U-Pb isotopic disturbance that is thought to be associated with granulite-grade metamorphism; consequently, the authors infer that the high-temperature metamorphism occurred before 1.81 Ga.

Muskoseu quartzite (PBA06-26B)

The sample is a quartz-rich rock with centimetre-scale layering defined by biotite-rich seams (Figure GS-8-2a). The proposed unconformable contact with basement is defined by a change to homogeneous, orthopyroxene-bearing tonalitic rocks. Zircons recovered from the quartzite are similar in appearance to those from the tonalite. A population of clear, colourless, high-quality prisms is present as distinct grains and rarely as overgrowths around a second population of light- to medium-brown, highly fractured, subrounded prisms. In contrast to the tonalite sample,

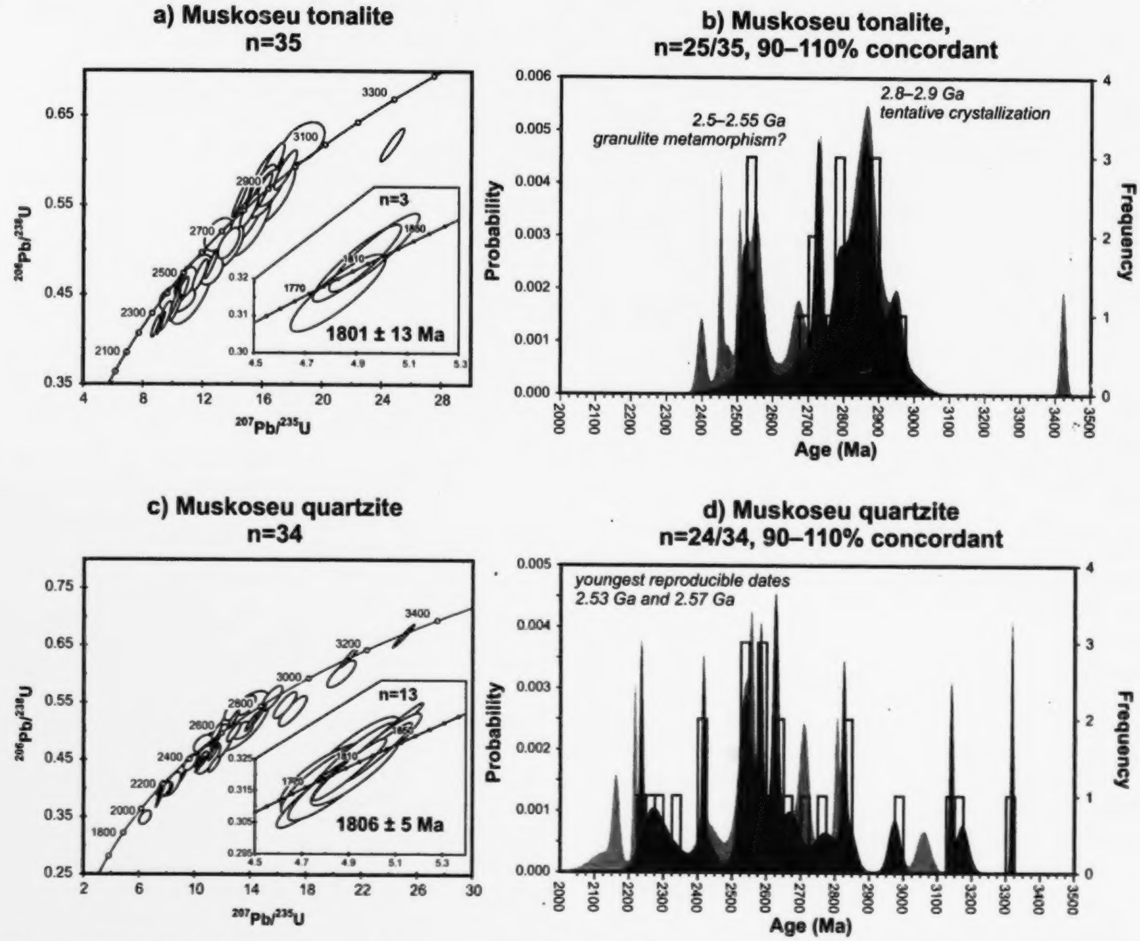


Figure GS-8-3: *Sensitive high-resolution ion microprobe (SHRIMP) U-Pb results for Muskoseu tonalite and overlying quartzite:* ***a)*** *Muskoseu tonalite concordia diagram, all data;* ***b)*** *Muskoseu tonalite probability density diagram with overlaid histogram; light grey shaded curve represents the probability density of the entire dataset (n = 35); dark grey shaded curve and histogram only illustrate results between 90 and 110% concordant and do not include replicate analyses (n = 25);* ***c)*** *Muskoseu quartzite concordia diagram, all data;* ***d)*** *Muskoseu quartzite probability density diagram with overlaid histogram; colour scheme as in* ***b)****.*

there is an approximate relationship between morphology and age, with the high-quality prisms routinely yielding ages consistent with Trans-Hudsonian metamorphism. The analysis of 13 zircon overgrowths or distinct prisms gave a weighted mean ^{207}Pb/^{206}Pb age of 1806 ±5 Ma (2σ, MSWD = 1.2, probability of fit = 26%; Figure GS-8-3c), which was interpreted as the time of metamorphism. These zircons exhibit faint concentric zoning and have Th/U ratios between 0.02 and 0.43. From the low-quality zircon population, interpreted to be detrital, 27 analyses were carried out on 20 separate zircon grains. Of the seven grains with replicate analyses, only three grains gave reproducible ages. Uranium-lead SHRIMP results for the detrital zircons are affected by the disturbance of the U-Pb systematics typically observed in granulite-grade rocks discussed previously. All non-reproduced dates should be considered as minimum ages. In the instance of multiple analyses from single zircon grains, the oldest of the replicate analyses is considered the minimum age. The detrital ages range from 2132 to 3318 Ma (DRI2007002; Figure GS-8-3c, d). The youngest reproducible zircon dates are ca. 2.53 Ga (grain 61) and 2.57 Ga (grain 30). The significance of these dates is ambiguous—they might correspond to the youngest detrital zircons or might be related to the ca. 2.5 Ga metamorphism proposed for the underlying tonalite described earlier. The significance of any of the younger early Paleoproterozoic ages is uncertain and should not be taken to represent the maximum age of deposition of the quartzite.

Wuskwatim charnockite (WX04-T050)

A sample of massive, brown-weathering, coarse-grained, orthopyroxene-biotite granite (charnockite) was collected on Wuskwatim Lake from a locally gneissic unit that includes schlieren of older gneiss. Previous Sm-Nd analyses indicated an evolved source with a model age of 3.1 Ga (Percival et al., 2006). Zircons recovered from the sample are mainly poor-quality, highly fractured prisms with numerous inclusions and some altered domains. A smaller proportion of the zircons, observed both as discrete crystals and overgrowths, are high-quality, clear, colourless zircon, typically unzoned in BSE images.

Thirty-four analyses were carried out on 26 individual zircon grains (DRI2007002; Figure GS-8-4). Six analyses from the clear, colourless zircons yielded a weighted mean $^{207}Pb/^{206}Pb$ age of 1804 ±29 Ma (2σ, MSWD = 0.14, probability of fit = 98%), interpreted to represent the timing of a late Trans-Hudson metamorphic overprint. One analysis (9216-37.2) gave a slightly older age of 1888 Ma, but this is likely due to overlap of the analytical spot onto an older core (9216-37.1). Zircon of pre–Trans-Hudson age exhibits the non-reproducible behaviour described earlier. Ages range from 2234 to 3248 Ma, with two dominant populations (Figure GS-8-4b). No distinction can be made between these two groups based on U concentration or Th/U ratio. Of the younger subset of data, zircon that is unzoned and between 2560 and 2662 Ma in age gives a weighted mean $^{207}Pb/^{206}Pb$ age of 2641 ±23 Ma (n = 10, MSWD = 0.44, probability of fit = 92%). By incorporating the five next-oldest analyses of faintly zoned to zoned zircon, it is possible to calculate a statistically indistinguishable weighted mean $^{207}Pb/^{206}Pb$ age of 2666 ±27 Ma (MSWD = 1.6, probability of fit = 6%). The current dataset, with its large errors and non-reproducible behaviour, is not adequate to convincingly state whether the difference in zonation pattern represents a true difference in age. Therefore, this population is best constrained in the age range of 2.64–2.66 Ga. The oldest population of zircon ranges in age from 3091 to 3248 Ma. The weighted mean $^{207}Pb/^{206}Pb$ age of the six oldest analyses (excluding one replicate analysis, 9216-43.1) is 3238 ±15 Ma (MSWD = 0.24, probability of fit = 94%). Two interpretations of the Archean dates from the charnockite are possible. In the first interpretation, the granite was intruded at 3.24 Ga and subsequently metamorphosed to granulite grade between 2.64 and 2.66 Ga. Alternatively, this is a magmatic charnockite crystallized between 2.64 and 2.66 Ga with 3.24 Ga inheritance. The latter interpretation is preferred due to the apparent freshness of the unit; however, the isolated nature of the outcrop (on a poorly exposed island in Wuskwatim Lake) limits the utility of field relationships to resolve this question.

Tullibee Lake tonalite gneiss (PBA06-91)

The Tullibee Lake sample is a finely laminated tonalitic gneiss containing pyroxene and cut by mafic dikes. During remapping, it was assumed to be of Molson age (1880–1884 Ma; Heaman et al., 1986; Hulbert et al., 2005; Figure GS-8-2b, c). The tonalite gneiss coincides with a positive aeromagnetic anomaly. This association with presumed older dikes and aeromagnetic highs led to the hypothesis of this rock type being Archean basement. Isotopic and geochronological studies on a nearby granodiorite gneiss yielded an ε_{Nd} value of –13 (*illustrated in* Percival et al., 2005), suggesting the presence of Archean rocks. The recovered zircon is typically slightly rounded and ranges in size from ~30 to 210 µm. Morphologies range from equant to prismatic. Most of the zircons are simply terminated, though some of the more equant grains are multifaceted. Approximately half of the grains are clear and colourless; the remainder range from light to very dark brown. Opaque inclusions are present in many grains. These inclusions are commonly surrounded by radial fractures. The intense brightness of these inclusions suggests high-density minerals such as uraninite and/or thorite.

Twenty-four analyses were performed on 17 separate zircon grains spanning the range of morphologies. The weighted mean $^{207}Pb/^{206}Pb$ age from 20 of the analyses is 1809 ±3 Ma. Both apparent cores and rims were targeted for analysis, but no difference in age or composition was observed (Figure GS-8-5).

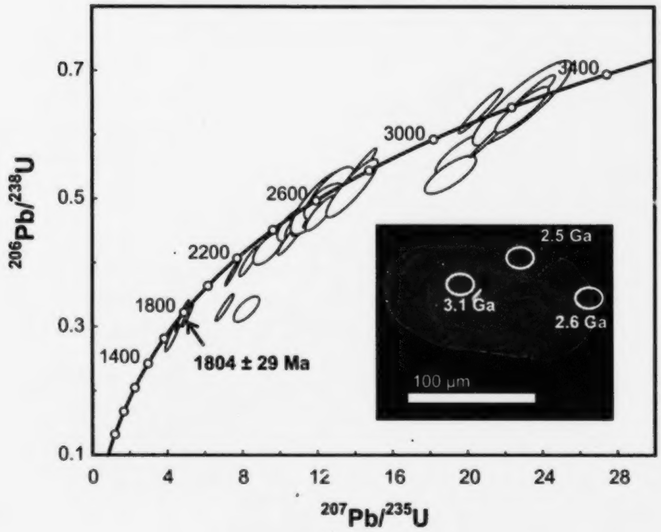
The four excluded analyses were replicates from a single zircon, grain 87 (Figure GS-8-5 inset), and a weighted mean of the three oldest analyses yielded a $^{207}Pb/^{206}Pb$ age of 1890 ±8 Ma (MSWD = 0.92, probability of fit = 40%). Grain 87 is morphologically distinct from the other grains, having a very irregular habit and interior alteration pattern.

Such a young dominant population of zircons from this sample was unexpected, given the presence of crosscutting mafic dikes and the magnetic signature of the area. Geochronological results from the three previous samples indicate that a metamorphic overprint at ca. 1.81 Ga is common in this region. If the 1809 Ma date from the Tullibee tonalite gneiss is also interpreted as metamorphic, the only constraint on any older components is the single grain dated at 1877 Ma. In this instance, it should only be considered a minimum age due to the apparent pervasiveness of the Paleoproterozoic overprint. The authors propose that any primary igneous zircons from the tonalite were either very rare or were resorbed during Trans-Hudson overprint; consequently, the age of this unit cannot be further constrained at this time.

Discussion

Results from earlier mapping, aeromagnetic surveys and geochronology studies led to the interpretation that the northeastern Kisseynew Domain is interleaved with or underlain by Superior basement and possibly Ospwagan Group cover (Percival et al., 2006; Zwanzig et al., 2006; this study). Although the presence of Archean basement is suggested from previous isotopic tracer work (Percival et al., 2006), the U-Pb results presented here provide rigorous confirmation. Questions remain, however, about the nature of the basement. Is the basement contiguous, or

a) Wuskwatim charnockite
n=34



b) Wuskwatim charnockite
n=19/27, 90–110% concordant

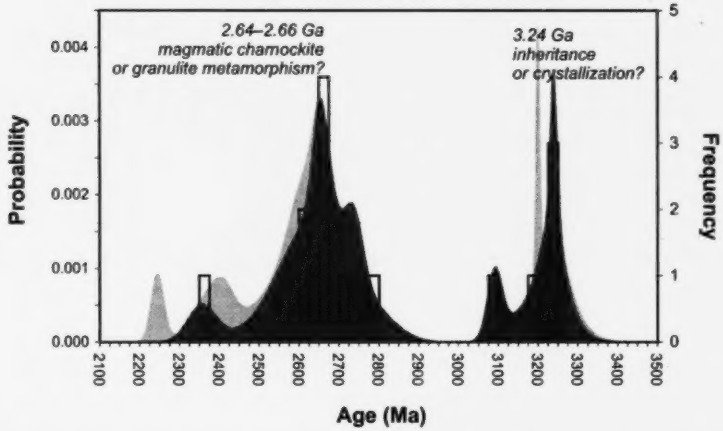


Figure GS-8-4: *Sensitive high-resolution ion microprobe (SHRIMP) U-Pb results for the Wuskwatim charnockite:* ***a)*** *concordia diagram, all data; inset is a backscattered electron (BSE) image of grain 9 illustrating analytical sites and spot ages, including a 3.1 Ga core and non-reproducible overgrowth dates;* ***b)*** *probability density diagram with overlain histogram; light grey shaded curve represents the probability density of the entire dataset (n = 27); dark grey shaded curve and histogram only illustrate results between 90 and 110% concordant and do not include replicate analyses (n = 19).*

a rifted fragment? If rifted, is it possible to discriminate between those of Superior craton affinity or slivers of other exotic blocks (i.e., Sask craton, Hearne margin and Wollaston Domain)?

The difficulty in constraining precise crystallization ages for the basement due to the isotopic disturbance of the zircons during >1.81 Ga granulite-facies metamorphism makes correlating basement ages with a specific craton challenging. Broadly speaking, the observed ages (2.8–3.4 Ga) are consistent with a Superior Province affinity (Figure GS-8-6). The presence of a 1.88 Ga isotopically contaminated plutonic suite (Percival et al., GS-7, this volume), as has been documented in the contiguous Superior Province (Percival et al., 2005), also argues for a correlation with that craton. Dates reported for the Sask craton are dominated by 2.45 Ga ages, with rocks as old as 3.1 Ga (Chiarenzelli et al., 1998; Ashton et al., 1999; Rayner et al., 2005). These dates do not appear to be consistent with those from the northeastern Kisseynew Domain; however, this may reflect limited exposure and sampling of the Sask craton at the surface. There are few lithological or age similarities with the Hearne margin

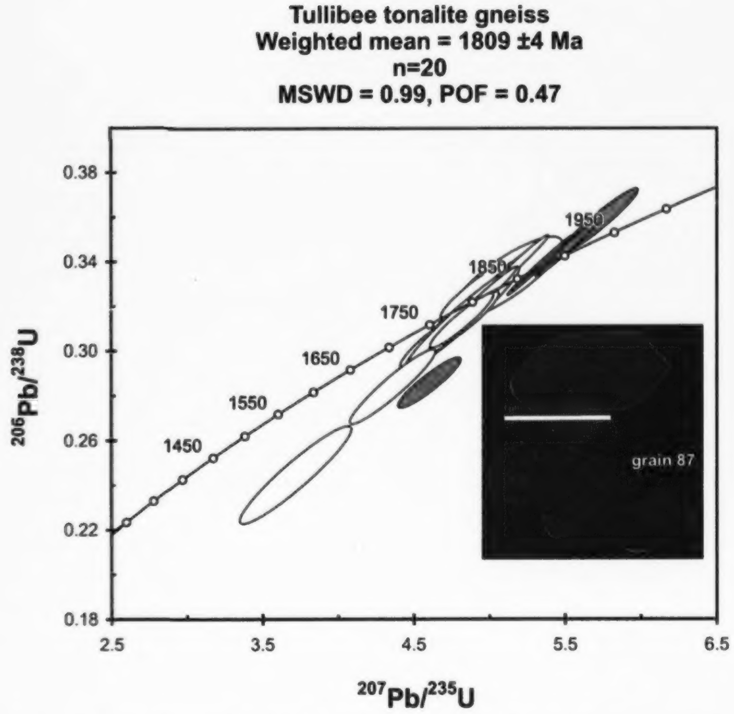


Figure GS-8-5: *Concordia diagram presenting sensitive high-resolution ion microprobe (SHRIMP) U-Pb results for Tullibee Lake tonalite gneiss; inset is a backscattered electron (BSE) image of a typical zircon from this sample (upper) and anomalous zircon grain 87 (lower) along with the locations of SHRIMP analyses. Data from grain 87 are shown by the light grey ellipses and are excluded from the calculation of the weighted mean. See text for discussion.*

in northeast Saskatchewan, where basement inliers are dominated by 2.57–2.59 Ga crystallization ages and basal Wollaston Domain detritus is dominated by 2.51–2.6 Ga zircon (Hamilton and Delaney, 2000).

By examining the correlation of the Muskoseu and Burntwood River sedimentary rocks (Figure GS-8-6c, b, respectively) with the Ospwagan Group (Figure GS-8-6a), it may be possible to shed light on the question of a continuous or rifted Superior craton. A stratigraphic and geochemical comparison of Ospwagan Group rocks from Thompson, Burntwood Group metasedimentary rocks and Muskoseu metasedimentary rocks suggests that the latter are broadly similar to the Ospwagan Group sedimentary rocks, with some problematic aspects (Zwanzig et al., 2006). That the Ospwagan Group is dominated by 2.7 Ga detritus, while the sedimentary rocks within the inliers regularly exhibit a significant, additional older detrital zircon component can be accounted for by changes in the source region (Figure GS-8-6). Similar detrital zircon ages have been documented in metasedimentary rocks of the Assean Lake Crustal Complex, a crustal block inferred to be exotic to the Superior craton prior to accretion to the margin at 2.6 Ga (Figure GS-8-6; Böhm et al., 2003). Another difference is that the isotopic disturbance in the basement and cover inlier samples is not observed in the Ospwagan Group rocks. This suggests a distinct metamorphic history for pre-Kisseynew Domain rocks west of Thompson. As the ca. 1.81 Ga zircons from the basement and cover samples exhibit 'normal' isotopic behaviour, the authors infer that a high-grade metamorphic event must have occurred before this time. If these rocks are correlative with the Ospwagan Group, they would have been deposited sometime after 1974 Ma (Hamilton and Bleeker, 2002), constraining an episode of high-grade metamorphism of the basement-cover assemblage to between 1.97 and 1.81 Ga. If the metamorphic event is also responsible for the granulite-grade assemblages in the Burntwood Group metasedimentary rocks and the formation of the structural culminations that preserve the basement rocks, the timing could be further constrained to between 1.83 and 1.81 Ga, the maximum age of deposition of the Burntwood Group (Percival et al., 2005, 2006; Growdon et al., 2006). If it can be demonstrated that detrital zircon from a basal sample of the Burntwood Group also exhibits the unusual analytical behaviour, this hypothesis would be strengthened. Should Burntwood Group zircon not exhibit this behaviour, an older, high-grade metamorphic event is needed to explain the data. A metamorphic event older than 1974 Ma would exclude a correlation with the Ospwagan Group *sensu stricto* and would be consistent with (but not exclusive to) earlier deposition on an isolated continental fragment.

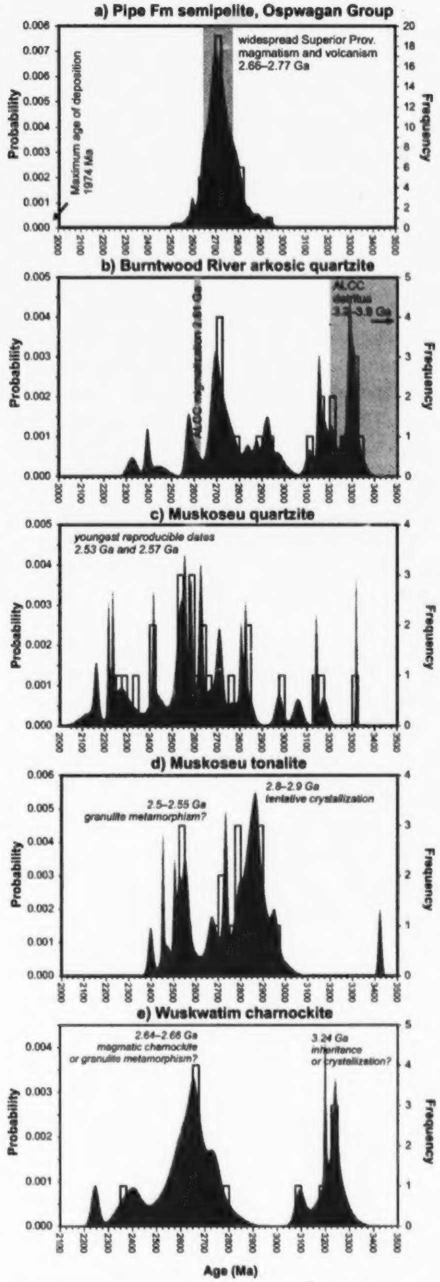


Figure GS-8-6: Comparison of pre-Kisseynew Domain basement and cover ages with typical Superior craton and Ospwagan Group detrital zircon ages. Probability density curves illustrate the entire dataset, including replicate analyses and discordant results. Overlaid histograms do not include replicate analyses or discordant results. Sources of data: ***a)*** *Rayner et al. (2005); maximum age of Ospwagan deposition data from Hamilton and Bleeker (2002); widespread Superior Province magmatism data from Corfu and Davis (1992);* ***b)*** *Zwanzig et al. (2006); abbreviation: ALCC, Assean Lake Crustal Complex; data from Böhm et al. (2003);* ***c), d), e)*** *this study.*

A greater understanding of early metamorphic events and the processes involved in the isotopic disturbance observed in pre–1.81 Ga zircon grains from the Kisseynew Domain inliers is required, as the current evidence does not rule out the possibility that these supracrustal rocks correspond to an early cover sequence preserved on a rifted Superior margin fragment.

Economic considerations

Uranium-lead zircon geochronology results presented provide compelling evidence of Archean basement rocks present in the northeastern quadrant of the Proterozoic Kisseynew Domain. This raises the possibility of enhanced diamond potential if the Archean mantle lithosphere is preserved. Although a definitive correlation between Ospwagan-type supracrustal rocks within the Kisseynew Domain and Ospwagan Group *sensu stricto* has not been made, the possibility of Thompson-type orebodies is still present. Although the details differ, the general lithological association of basement and supracrustal rocks (including iron formation and mafic sills) in the Wuskwatim Lake–Burntwood River area and possibly the Tullibee–Neuls lakes area is similar to that observed in the Thompson Nickel Belt.

Acknowledgments

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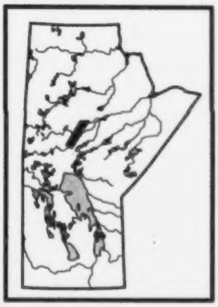
GS-9

Hudsonian regional metamorphism in the Thompson Nickel Belt, Manitoba (parts of NTS 63J15, 16, 63O1, 2, 8, 9, 16, 63P12, 13, 64A4)

by C.G. Couëslan[1], D.R.M. Pattison[1] and J.J. Macek



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Summary

This report is part of a continuing Ph.D. study on the regional metamorphism of the Thompson Nickel Belt. Metapelitic rocks in the majority of the belt are characterized by upper-amphibolite–facies mineral assemblages (biotite–K-feldspar–sillimanite±garnet). In the northern half of the belt is a central, northeast-trending, trough-like metamorphic low of middle-amphibolite–grade, muscovite- and quartz-bearing metapelitic rocks. The zone of middle-amphibolite–grade rocks extends from the Moak–Mystery lakes area southward beneath the city of Thompson and to the Ospwagan Lake–Pipe mine area. Metamorphic grade increases northwest and southeast away from the central trough. Zones of granulite-facies rocks occur along the northwest margin of the Thompson Nickel Belt and in the Mel Zone–Strong Lake area. These zones are characterized by biotite–cordierite–garnet–K-feldspar metapelitic assemblages and orthopyroxene-bearing semipelitic rocks. The rocks of highest metamorphic grade occur in the Phillips Lake area and in a small zone near Hambone Lake, where orthopyroxene occurs in semipelitic rocks and has been tentatively identified in metabasic rocks. Samples of Ni-Cu ore were collected from the Thompson, Birchtree and Pipe mines to examine the effects of metamorphism on the orebodies.

It is hoped that a better understanding of metamorphism in the Thompson Nickel Belt will lead to a better understanding of the tectonic evolution of the belt. This will lend itself to a greater comprehension of the Trans-Hudson Orogen in Manitoba and to improved exploration strategies. Documenting the Ospwagan Group at various metamorphic grades may help with the identification of these rocks during exploration programs, especially in portions of the belt that have been subjected to higher grades of metamorphism. Differences in metamorphic grade may also have an effect on the mobilization of ore through solid-state, hydrothermal and anatectic processes.

Introduction

The 400 km long by 10–35 km wide, northeast-trending Thompson Nickel Belt (TNB) occurs along the northwestern margin of the Superior craton (Bleeker, 1990a; Hulbert et al., 2005). As part of the Superior Boundary Zone, the TNB marks a segment of the collisional zone between the Superior craton and the juvenile terranes of the Trans-Hudson Orogen. The TNB begins 70 km northeast of Thompson (Zwanzig, 2005) and continues southwest, with the southern half of its total length covered by Phanerozoic rocks. The southeastern margin of the exposed portion of the belt is gradational with the Pikwitonei Granulite Domain. Its northwestern margin is bounded by the Kisseynew Domain of the Trans-Hudson Orogen internal zone.

The TNB is dominated by variably reworked Archean basement gneiss with minor Paleoproterozoic supracrustal and intrusive rocks (Bleeker 1990a, b; Weber, 1990; Hulbert et al., 2005). The Archean basement consists largely of migmatitic gneiss that is believed to be derived from retrogressed Pikwitonei granulite (Russell, 1981; Bleeker, 1990b; Machado et al., 1990; Weber, 1990; Lettley, 2001). The Archean basement gneiss is unconformably overlain by metasedimentary and metavolcanic rocks of the Paleoproterozoic Ospwagan Group (Bleeker and Macek, 1988; Bleeker, 1990a, c). The supracrustal rocks occur in deeply dissected, regional-scale folds or fault slices (Bleeker, 1990a; Weber, 1990).

The Ospwagan Group supracrustal sequence consists, from base to top, of the Manasan Formation, the Thompson Formation, the Pipe Formation, the Setting Formation and the Bah Lake volcanogenic assemblage (Bleeker and Macek, 1988; Bleeker, 1990a, c; McGregor et al., 2006). The Manasan Formation is a siliciclastic sequence of quartzite and semipelite that grades into the overlying Thompson Formation, which consists dominantly of calcsilicate and siliceous marble. The Pipe Formation consists of pelitic schist, sulphide- and silicate-facies iron formations, and siliceous and ferruginous metasedimentary rocks. The Setting Formation is a siliciclastic sequence of interlayered pelitic schist and quartzite. The Bah Lake assemblage consists of mafic to ultramafic volcanic flows with abundant dikes and sills (Zwanzig, 2005). Along the western margin of the TNB, Ospwagan Group rocks are juxtaposed against Burntwood Group metaturbidite of the Kisseynew Domain, with their contact interpreted to be a fault (Bleeker, 1990b).

This report summarizes work undertaken in 2007 as part of an ongoing Ph.D. study into the Hudsonian metamorphism of the TNB. The study began with fieldwork in the summer of 2006 and continued in 2007 with finalizing field studies at the Pipe mine and Ospwagan Lake, examining drillcore from throughout the belt and sampling to study the effects of Hudsonian metamorphism on the Molson dike swarm. In addition, samples of ore were also collected in 2007 from the Thompson, Birchtree and Pipe mines to examine the effects of metamorphism on the Ni-Cu deposits of the TNB.

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Metamorphism of Molson dikes

The Molson dikes are interpreted to predate Paleoproterozoic metamorphism of the TNB and postdate Archean metamorphic events that have affected the basement gneiss (Halls and Heaman, 2000). Assuming the Molson dikes to be of relatively constant composition, it may be possible to detect variations in metamorphic grade throughout the belt by examining changes in metamorphic mineral assemblages, augmented by phase equilibrium modelling using thermodynamic software such as PERPLEX (Connolly and Petrini, 2002). Samples of the Molson dikes that were collected from Sipiwesk Lake ranged from pristine gabbroic rock in the Pikwitonei Granulite Belt to hydrated and amphibolitized rock affected by varying degrees of deformation within TNB-type gneiss. Samples of plagioclase amphibolite, interpreted as metamorphosed Molson dikes, were obtained from numerous drillcores throughout the belt as well as from outcrop at the Pipe mine and in the Joey Lake area. Because the metamorphism at the Pipe mine is well constrained by spatially associated metapelite assemblages (Couëslan et al., 2006), three Molson dikes were sampled along an east–west transect starting east of the open pit, where metapelite rocks are microcline bearing, and finishing west of the pit, where they are quartz and muscovite bearing. Field examination of Molson dikes within the TNB revealed little mineralogical variation, with the exception of the occasional garnet and the possible presence of orthopyroxene in selected drillcores from the Hambone, Paint, Phillips and Strong lakes areas. Greater variations in mineral assemblages may become apparent in thin sections collected from these dikes.

Regional metamorphism

The majority of this summer's field activities involved logging of diamond-drill core, with a few outcrops visited at the Pipe mine, in the Joey Lake area and at Ospwagan and Paint lakes. Drillcore was examined at CVRD Inco Exploration in Thompson and Crowflight Minerals Inc. in Wabowden. Much of the examined core was telescoped, consisting of 2–6 in. (5–15 cm) lengths of core that had been sampled approximately every 10 ft. (3 m). The locations of the studied drillholes were selected to gain information in areas where suitable outcrop is not available, and in an attempt to improve the resolution of interpreted changes in metamorphic grade. The examined core was also selected based on the rock types described in the original core logs, with emphasis being placed on metapelitic rocks and iron formations. The results presented here are based largely on the metamorphic assemblages visible in core and hand sample, and thus should be regarded as preliminary and requiring verification using the microscope and other analytical techniques.

Metamorphic isograds

The majority of the TNB is characterized by upper-amphibolite–facies rocks; however, rocks of middle-amphibolite facies occur in a northeast-trending, trough-like zone that is generally subparallel to the trend of the belt (Figure GS-9-1). Middle-amphibolite–facies metapelitic rocks are characterized by the presence of biotite, muscovite, quartz garnet, staurolite, andalusite and sillimanite. The isograd marking the boundary between middle-amphibolite and upper-amphibolite facies is manifested by the breakdown of coexisting muscovite and quartz to form potassium feldspar, sillimanite and a melt or vapour phase. Middle-amphibolite–facies metapelitic rocks can be further subdivided into lower and higher middle-amphibolite facies by a sillimanite isograd (the prograde formation of sillimanite through the breakdown of andalusite and/or staurolite). Zones of granulite-facies rocks are also present in the belt. These high-grade zones generally occur towards the periphery of the belt and are subparallel to the overall trend of the TNB. The upper-amphibolite– to granulite-facies transition is marked by the appearance of coexisting cordierite and garnet in metapelite and the presence of orthopyroxene in semipelite and metabasite (Pattison et al., 2003).

Middle-amphibolite–facies rocks are recognized in the Moak–Mystery lakes area, under the city of Thompson, in the Ospwagan Lake–Pipe mine area, and in an area north of Soab Lake (Figure GS-9-1). Rocks in the Ospwagan Lake–Pipe mine area are staurolite and andalusite bearing, and appear to be among the lowest grade metamorphic rocks in the belt (Figure GS-9-2). Metapelitic rocks in the Moak–Mystery lakes area and Soab Lake area contain sillimanite, indicating higher metamorphic grade.

Granulite-facies rocks are recognized along the northwest margin of the TNB and Mel Zone–Strong Lake area; in the Phillips Lake area possibly extending to southern Paint Lake; and in a small zone in the Joey Lake area. At the highest metamorphic grades, the Ospwagan Group metasedimentary rocks may become highly recrystallized such that they are almost indistinguishable from the Archean basement gneiss. In these instances, Thompson Formation marble and calcsilicate rocks, and Pipe Formation iron formation and sulphidic sedimentary rocks become important marker horizons for distinguishing and identifying Ospwagan Group metasedimentary rocks (McGregor et al., 2006).

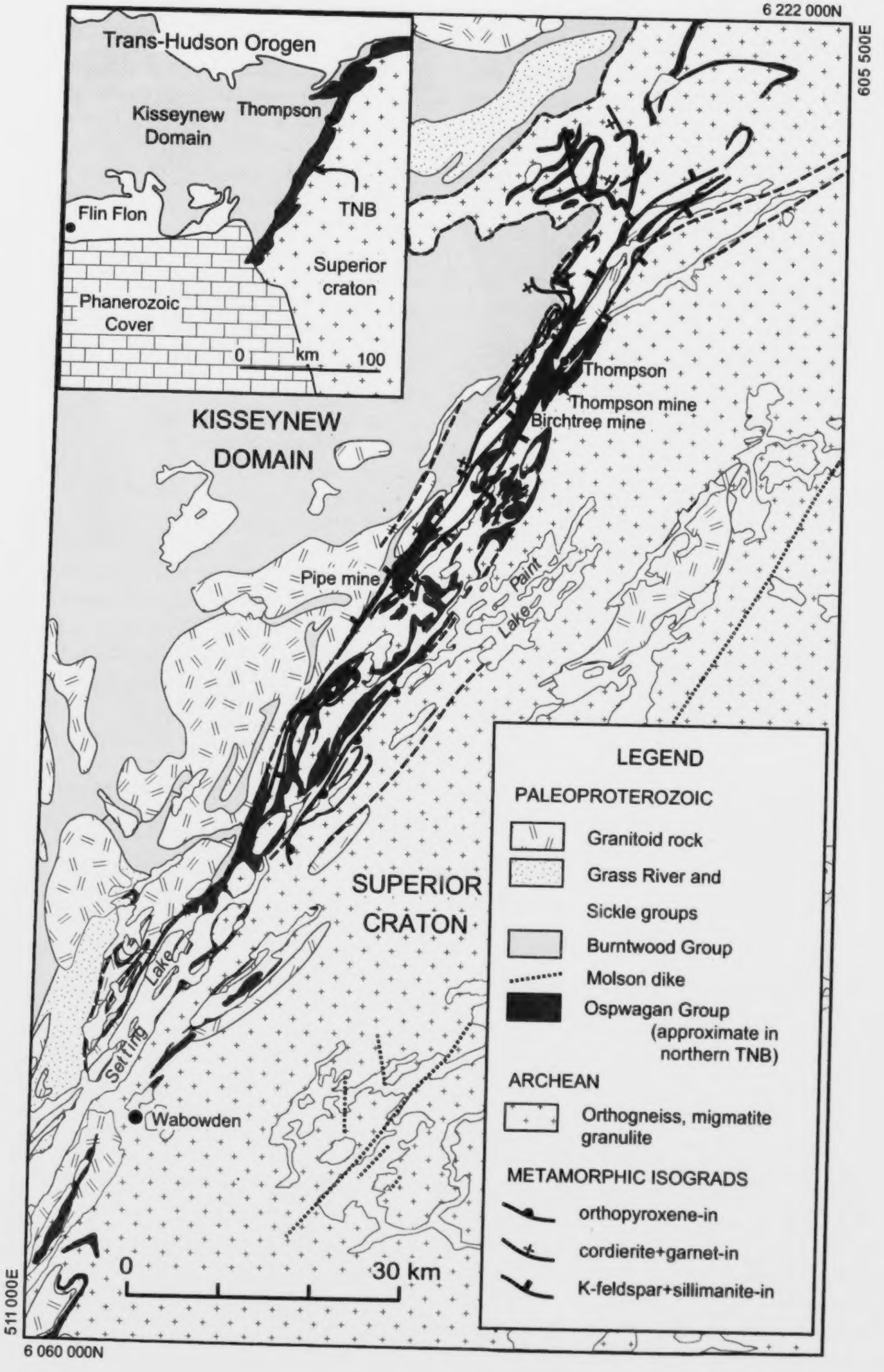
6 222 000N
605 500E
Trans-Hudson Orogen
Kisseynew Domain
Thompson
TNB
Flin Flon
Superior craton
Phanerozoic Cover
0 km 100
KISSEYNEW DOMAIN
Thompson
Thompson mine
Birchtree mine
Pipe mine
Paint Lake
SUPERIOR CRATON
Setting Lake
Wabowden
0
30 km
511 000E
6 060 000N
LEGEND
PALEOPROTEROZOIC
Granitoid rock
Grass River and Sickle groups
Burntwood Group
Molson dike
Ospwagan Group (approximate in northern TNB)
ARCHEAN
Orthogneiss, migmatite granulite
METAMORPHIC ISOGRADS
orthopyroxene-in
cordierite+garnet-in
K-feldspar+sillimanite-in

Figure GS-9-1: *Regional geology of the exposed portion of the Thompson Nickel Belt (Zwanzig, 2005). The K-feldspar+ sillimanite in isograd marks the boundary between middle-amphibolite– and upper-amphibolite–facies metamorphism in metapelitic rocks. The boundary between upper-amphibolite– and granulite-facies metamorphism is marked by the cordierite+garnet in isograd in metapelitic rocks, and the orthopyroxene in isograd in semipelitic and metabasic rocks.*

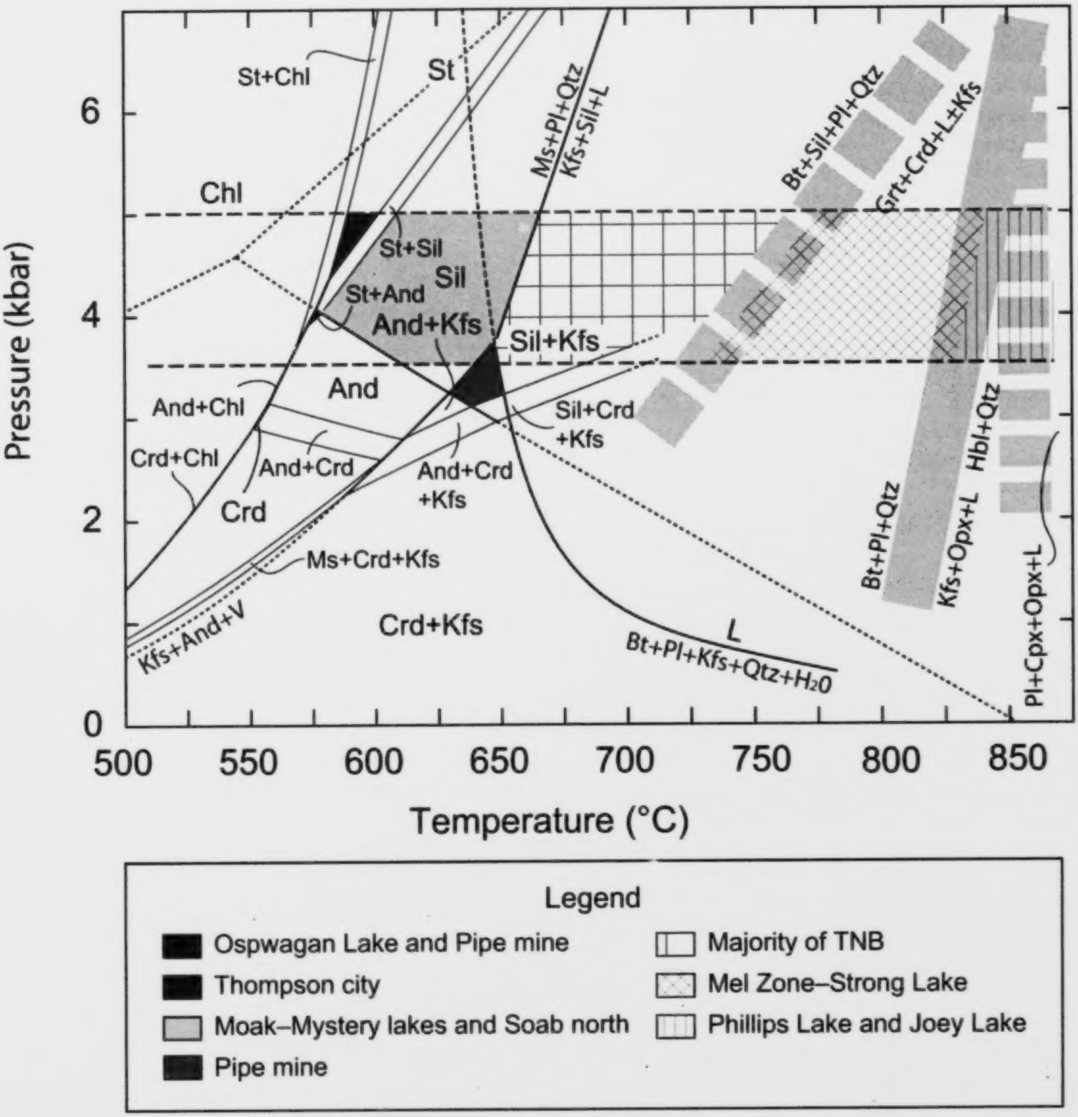

***Figure GS-9-2:** Petrogenetic grid showing the metamorphic conditions for mineral assemblages found in the Thompson Nickel Belt. The phase relationships in black lines are for average pelite in the system K_2O-FeO-MgO-Al_2O_3-SiO_2-H_2O (Pattison and Vogl, 2005), with broken lines representing metastable assemblages. The reaction curves Ms+Pl+Qtz↔Kfs+Sil+L and Bt+Pl+Kfs+Qtz+H_2O↔L and the broad reaction curves in light grey are from Pattison et al. (2003). Mineral abbreviations: And, andalusite; Bt, biotite; Chl, chlorite; Cpx, clinopyroxene; Crd, cordierite; Grt, garnet; Hbl, hornblende; Kfs, potassium feldspar; L, silicate liquid; Ms, muscovite; Opx, orthopyroxene; Pl, plagioclase; Qtz, quartz; Sil, sillimanite; St, staurolite; V, vapour.*

Pressure and temperature constraints

Pressure-temperature conditions for middle-amphibolite–facies rocks can be constrained based on a thermodynamically modelled petrogenetic grid for world average pelite (Pattison and Vogl, 2005; Figure GS-9-2). The best pressure and temperature constraints in the TNB come from the Pipe mine–Ospwagan Lake area. Peak metamorphic assemblages present in the Pipe Formation metapelite at Ospwagan Lake consist of andalusite–biotite–muscovite–plagioclase–quartz–staurolite±garnet. This assemblage implies temperatures in the range 550–600°C at a pressure of ~4 kbar. A similar assemblage is also present at the Pipe mine. It appears, however, that the Pipe mine was subjected to a relatively steep thermal gradient because approximately 300 m east of the outcrop containing the above assemblage, metapelite horizons in the Setting Formation outcrops contain the metamorphic assemblage biotite–K-feldspar–plagioclase–quartz–sillimanite±garnet (Figure GS-9-3). The K-feldspar appears to have crystallized without the presence of a silicate melt (Couëslan et al., 2006), suggesting temperatures of 610–660°C and a pressure of ~3–4 kbar.

The mineral assemblages in other parts of the TNB provide less constraint on pressure; however, the pressure values indicated above are similar to those obtained by other workers in the belt. Russell (1981) estimated pressures of 4.0–5.0 kbar at Paint Lake using garnet-sillimanite-quartz-plagiolase geobarometry; alternatively, Paktunç and Baer (1986) suggested a pressure of 3.3–4.1 kbar utilizing the same dataset. Paktunç and Baer (1986) also estimated a pressure of 4.8 kbar at the Thompson mine, using garnet-sillimanite-quartz-plagioclase geobarometry. In contrast, Bleeker (1990a) suggested higher pressures of 6.0–7.0 kbar at the Thompson mine and 5.0–6.0 kbar at the Pipe mine.

Assuming the metamorphic pressures in the belt to be between 3.5 and 5.0 kbar, a range of temperatures can be assigned to various parts of the belt (Figure GS-9-2). The majority of metapelitic rocks in the TNB are migmatitic and contain abundant biotite, quartz, K-feldspar and sillimanite±garnet. Such a metamorphic assemblage suggests upper-amphibolite–grade metamorphism and temperatures of ~650–750°C. The lower-grade, middle-amphibolite–facies metapelitic rocks present in the Moak–Mystery lakes area contain sillimanite and muscovite, and reached ~580–650°C. Samples of the Pipe Formation metapelite from beneath the north end of the city of Thompson are staurolite, biotite and muscovite bearing but Al_2SiO_5 free, indicating temperatures of ~575–600°C and pressures above ~4 kbar. Higher grade granulite-facies rocks along the northwest margin of the belt and in the Mel Zone–Strong Lake area attained temperatures of ~725–850°C and are garnet- and cordierite-bearing metapelitic rocks and biotite- and orthopyroxene-bearing semipelitic rocks. The highest temperature rocks occur in the Phillips and Joey lakes areas, where semipelitic rocks contain orthopyroxene and biotite, and orthopyroxene has been tentatively identified in metabasic rocks. In these areas, temperatures may have reached in excess of 800°C.

In general, it appears that the southern half of the exposed portion of the TNB is characterized by widespread, upper-amphibolite– to granulite-facies metamorphism. In contrast, the northern half of the belt is characterized by a trough-like metamorphic low that is oriented to the northeast, subparallel to the trend of the belt. Temperatures appear to increase in either direction away from this central trough, reaching granulite grade along the contact of the TNB with the Kisseynew Domain.

Metamorphism of TNB ore deposits

Samples of Ni-Cu ore were collected from the Thompson, Birchtree and Pipe mines to investigate the effects of metamorphism on ore bodies in the TNB and explore the possibility of sulphide anatexis (cf., Tomkins et al., 2006). Samples of massive sulphide ore, as well as veins and veinlets of sulphide found crosscutting the metasedimentary country rock, were collected underground from the T1 deposit at the Thompson mine. Similar samples were collected underground at the Birchtree mine, along with samples of garnetite, which occurs locally in intimate association with the Ni-Cu ore (C. Pike, pers. comm., 2007). A single sample of ore, consisting of a 3 cm thick vein of massive sulphide in metaperidotite, was collected from the periphery of the open pit at the Pipe mine. Observations made underground suggested at least some of the crosscutting sulphide veins at the Thompson mine are the result of hydrothermal mobilization, as suggested by Chen et al. (1993).

Economic considerations

A better understanding of regional metamorphic data for the Thompson Nickel Belt will aid in the development of a regional tectonic framework for the belt. This is important both for a greater understanding of the Trans-Hudson Orogen in Manitoba and for exploration strategies within the TNB. The local grade of regional metamorphism may also be important, as it may have an effect on the mobilization of ore bodies through solid-state, hydrothermal and anatectic processes. Finally, metamorphic grade affects the characteristics of Ospwagan Group supracrustal rocks. A thorough documentation of their characteristics at different metamorphic grades will greatly increase the ability to recognize Ospwagan Group rocks that have been metamorphosed. This is significant for exploration in the TNB, because the most significant Ni deposits in the belt occur within the P1 and P2 members of the Pipe Formation.

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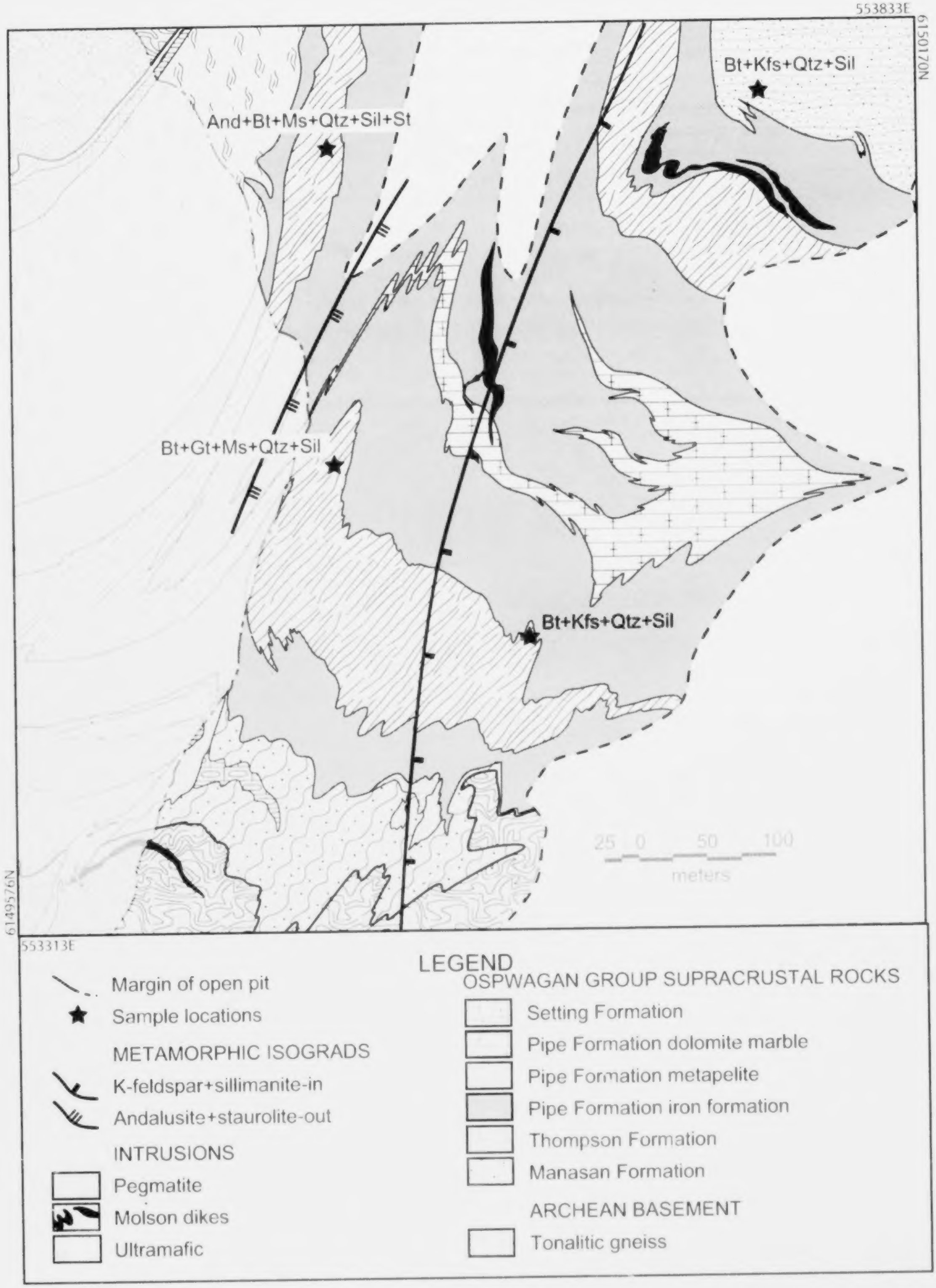
553833E
6150170N
Bt+Kfs+Qtz+Sil
And+Bt+Ms+Qtz+Sil+St
Bt+Gt+Ms+Qtz+Sil
Bt+Kfs+Qtz+Sil
25 0 50 100
meters
6149576N
553313E
LEGEND
Margin of open pit
Sample locations
METAMORPHIC ISOGRADS
K-feldspar+sillimanite-in
Andalusite+staurolite-out
INTRUSIONS
Pegmatite
Molson dikes
Ultramafic
OSPWAGAN GROUP SUPRACRUSTAL ROCKS
Setting Formation
Pipe Formation dolomite marble
Pipe Formation metapelite
Pipe Formation iron formation
Thompson Formation
Manasan Formation
ARCHEAN BASEMENT
Tonalitic gneiss

***Figure GS-9-3**: General geology along the eastern margin of the Pipe mine open pit. The metapelite mineral isograd K-feldspar+sillimanite in marks the boundary between middle-amphibolite–grade rocks to the west and upper-amphibolite–grade rocks to the east.*

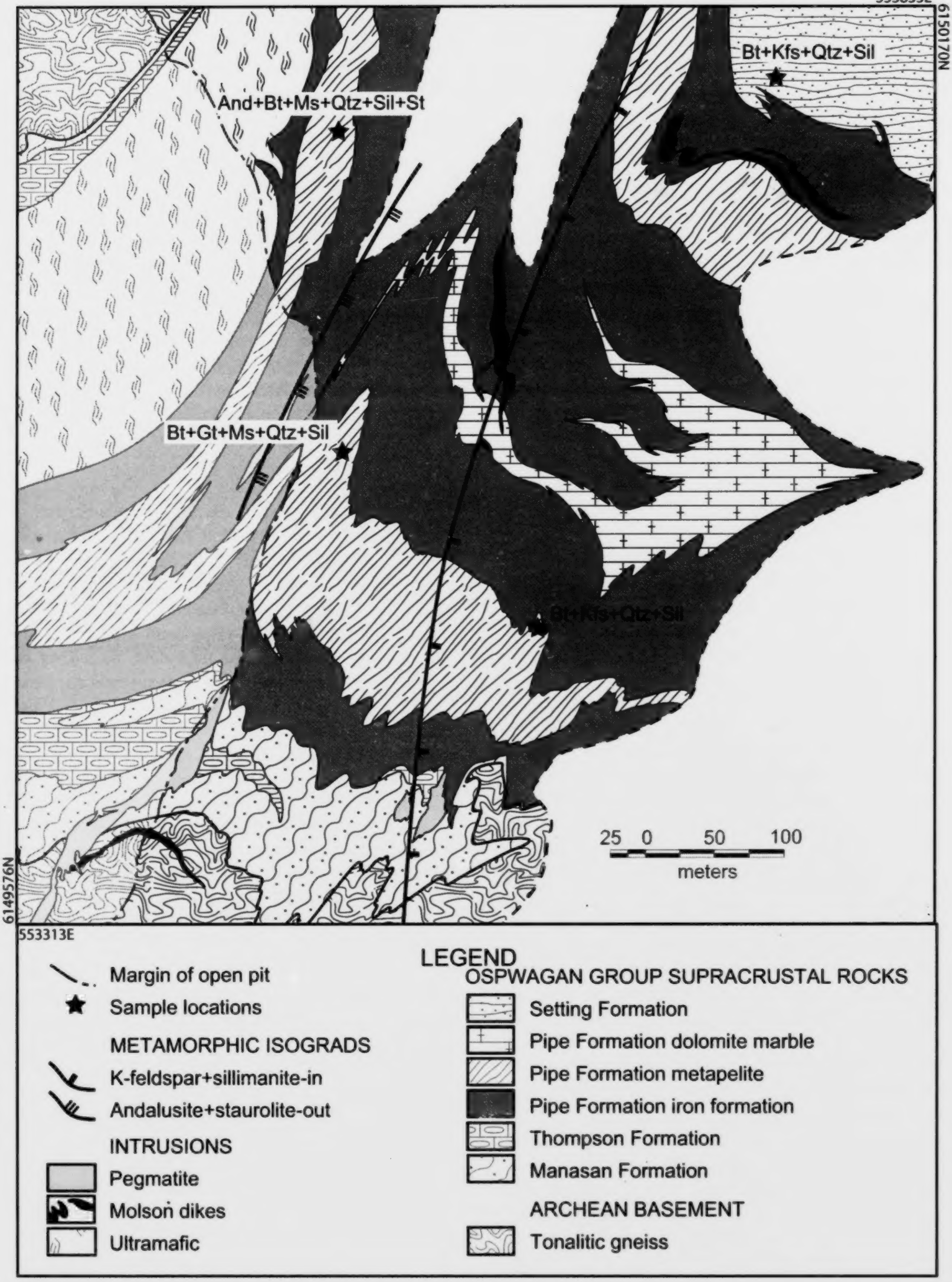
553833E
6150170N
Bt+Kfs+Qtz+Sil
And+Bt+Ms+Qtz+Sil+St
Bt+Gt+Ms+Qtz+Sil
Bt+Kfs+Qtz+Sil
25 0 50 100
meters
6149576N
553313E
LEGEND
Margin of open pit
Sample locations
METAMORPHIC ISOGRADS
K-feldspar+sillimanite-in
Andalusite+staurolite-out
INTRUSIONS
Pegmatite
Molson dikes
Ultramafic
OSPWAGAN GROUP SUPRACRUSTAL ROCKS
Setting Formation
Pipe Formation dolomite marble
Pipe Formation metapelite
Pipe Formation iron formation
Thompson Formation
Manasan Formation
ARCHEAN BASEMENT
Tonalitic gneiss

Figure GS-9-3: *General geology along the eastern margin of the Pipe mine open pit. The metapelite mineral isograd K-feldspar+sillimanite in marks the boundary between middle-amphibolite–grade rocks to the west and upper-amphibolite–grade rocks to the east.*

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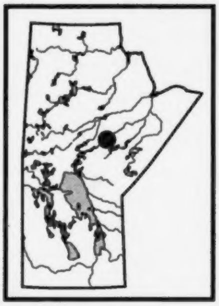
GS-10 Nature, evolution and gold potential of the Utik Lake greenstone belt, Manitoba (parts of NTS 53M4, 5, 63P1, 8): preliminary field results

by C.O. Böhm, P.D. Kremer and E.C. Syme



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Summary

An Archean mafic metavolcanic–dominated greenstone belt at Utik Lake, central Manitoba, was mapped and studied in detail to 1) determine the nature, age and composition of the supracrustal rocks, in order to compare them with greenstone belts elsewhere in the northwestern Superior Province (e.g., Knee and Oxford lakes areas); 2) analyze the kinematics and structural evolution of the Utik Lake greenstone belt; and 3) reassess the potential of the area to host volcanogenic massive sulphide and orogenic and epigenetic gold deposits.

The greenstone belt at Utik Lake is up to 12 km wide and forms an east- to northeast-trending, subvertically dipping and southward-facing homoclinal succession intruded and bounded by younger granitoid rocks. The greenstone belt can be subdivided into several east- to northeast-trending panels of mafic metavolcanic and mafic intrusive rocks that are separated by metasedimentary sequences, including iron formation, mudstone and mafic volcanic-derived conglomerate. The metavolcanic rocks at Utik Lake have compositional and textural similarities, occur along strike with, and may thus be correlative with mafic metavolcanic rocks of the ca. 2.83 Ga Hayes River Group at Knee Lake. In contrast, the felsic to intermediate, tuffaceous and volcanogenic sediment–dominated rocks of the supracrustal belts at nearby Bear and Oxford lakes likely form parts of the Neoarchean, ca. 2.73–2.71 Ga Oxford Lake Group.

The mafic metavolcanic and associated volcanogenic metasedimentary rocks at Utik Lake are overlain by a sequence of clastic sedimentary rocks that includes polymictic conglomerate, siltstone-mudstone turbidite, cordierite- and garnet-porphyroblastic wacke, and quartz arenite to sandstone. This younger metasedimentary sequence is similar in composition and tectonic position to the Opischikona metasedimentary rocks at central Knee Lake, whose age is estimated to be between 2.82 and 2.78 Ga. All supracrustal rocks at Utik Lake were intruded by at least three suites of felsic plutonic rocks of dominantly granitoid composition. Regional metamorphic grade is upper greenschist to amphibolite facies, with increased temperature conditions recorded in rocks (sillimanite zone in pelitic rocks) at the margins of the belt, likely due to contact metamorphism by the bounding plutonic rocks.

The voluminous mafic metavolcanic and igneous rocks at southwestern Utik Lake were locally pervasively altered by hydrothermal and fumarolic vein and dike systems that formed chemical seafloor sedimentary rocks (chert-magnetite iron formation), capped by auriferous chert and shale. The entire supracrustal assemblage was locally highly strained and sheared prior to, during and after the felsic plutonism that invaded and enveloped the supracrustal belt. The tectonic evolution of the belt is thus very favourable for orogenic and possibly epigenetic gold occurrences similar to those along regional strike at Knee Lake and Monument Bay.

Introduction

Utik Lake is located approximately 130 km southeast of Thompson, Manitoba, within the northwestern part of the Archean Superior Province. The lack of road access and distance to traditional mining camps (e.g., Thompson, Bissett) has limited the amount of geological and exploration work in the area, but previous geologists (Milligan, 1951; Milligan and Take, 1954; Hargreaves, 1975; Hargreaves and Ayres, 1979; Weber, 1975) have noted well-exposed mafic metavolcanic–dominated supracrustal sequences (greenstone) in the area. The supracrustal rocks have been regionally metamorphosed, but the prefix 'meta' is omitted in specific rock names (e.g., basalt) in the following discussion for purposes of brevity.

The greenstone belts at Utik and Bear lakes were selected for multidisciplinary stratigraphic, structural, geochronological and geochemical analyses because this part of the northwestern Superior Province has experienced little mineral prospecting and exploration attention during the past several decades. The present work aims to re-evaluate the mineral potential of this area, particularly the potential for orogenic and/or epigenetic gold deposits. The approach is to incorporate into existing map data the results from modern analytical and field techniques that were not available or applied during the previous mapping projects. The new data from the Utik Lake and Bear Lake greenstone belts can then be compared and integrated with those from the greenstone belts in the Knee and Oxford lakes areas (Figure GS-10-1).

Previous studies

The first geological survey work in the Utik–Bear lakes region was undertaken in the 1950s by Milligan (1952) and coworkers (Allen, 1953; Milligan and Take,

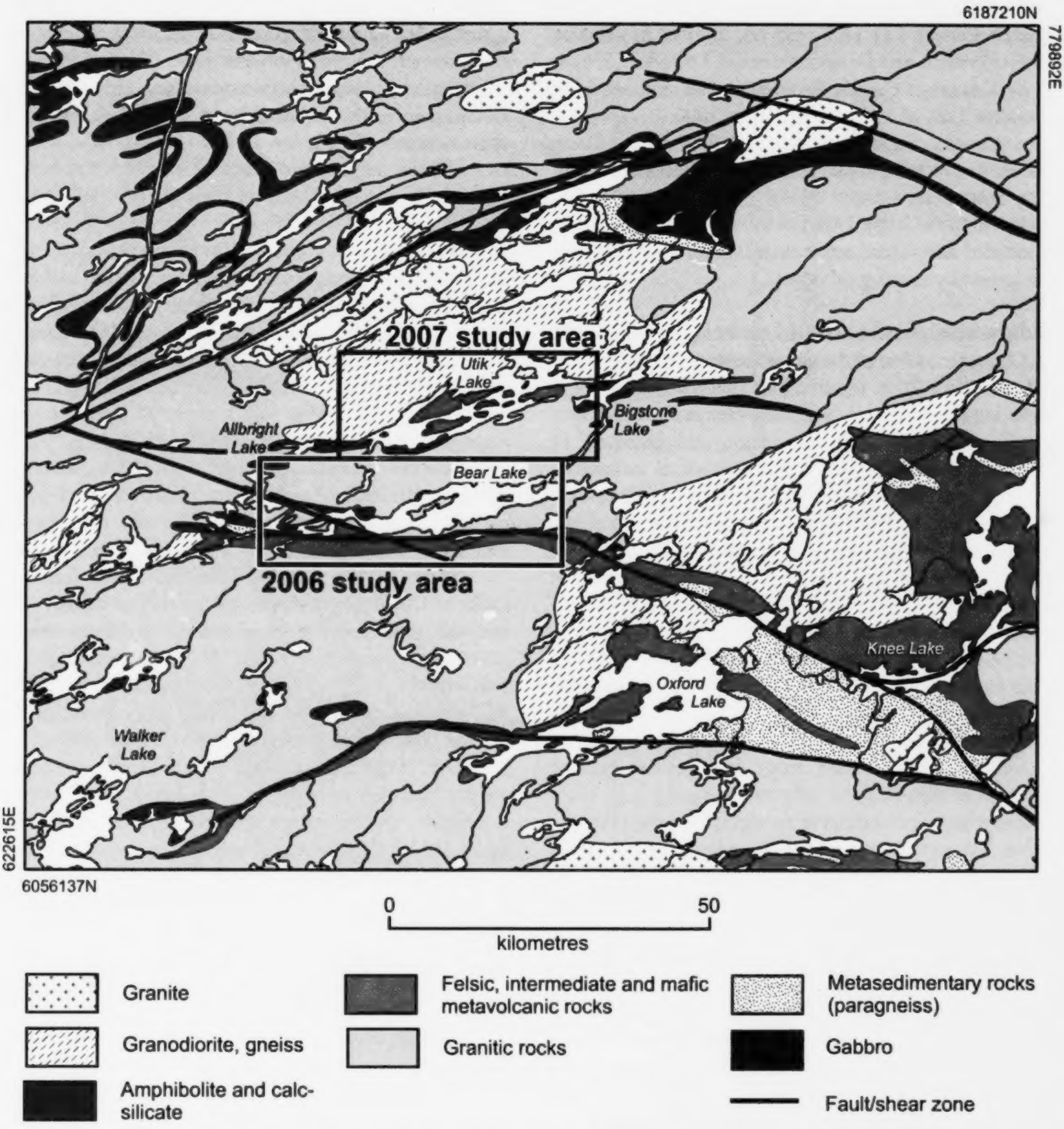
6187210N
779892E
2007 study area
Utik Lake
Bigstone Lake
Allbright Lake
Bear Lake
2006 study area
Knee Lake
Oxford Lake
Walker Lake
622615E
6056137N
0
50
kilometres
Granite
Felsic, intermediate and mafic metavolcanic rocks
Metasedimentary rocks (paragneiss)
Granodiorite, gneiss
Granitic rocks
Gabbro
Amphibolite and calc-silicate
Fault/shear zone

Figure GS-10-1: *Simplified regional geology of part of the northern Superior Province in Manitoba, with the Utik Lake (2007) and Bear Lake (2006) mapping areas outlined.*

1954). This early mapping (1:31 680 scale), combined with systematic prospecting for base and precious metals, represents a solid lithological framework for the larger study area, and resulted in the discovery of copper and gold showings. Subsequent investigations by Weber (1974, 1975) were aimed at subdivision of the supracrustal rocks into subunits and the development of a regional tectonic interpretation. In addition, Weber (1975) initiated studies of mafic metavolcanic flows and synvolcanic hydrothermal alteration pipes in the southern Utik Lake belt; these were followed up in more detail by Hargreaves and Ayres (1979) and Bernier and MacLean (1989).

Mineral exploration at Utik Lake experienced a minor spike in the mid- to late 1980s, when Westmin Exploration Ltd. examined some of the previously identified volcanogenic massive sulphide and gold occurrences in the Utik Lake mafic metavolcanic rocks (e.g., Assessment Files 94560, 94563, 94342, Manitoba Science, Technology, Energy and Mines, Winnipeg) and encountered significant zinc mineralization during their drilling campaigns (A.F. 94317, 94318). After that, minor prospecting and mineral exploration activities at Utik

Lake were part of regional surveys in 1998 by BHP Minerals Canada Ltd. (A.F. 73539); in 1999 by Hudson Bay Exploration and Development Co. Ltd. (A.F. 73614) and by Kennecott Canada Exploration Inc. and Montello Resources Ltd. (A.F. 73615); and in 2000–2001 by De Beers Canada Exploration Inc. (A.F. 94882). These regional heavy mineral and soil surveys detected encouraging anomalous mineral and/or element concentration trends within the larger Utik Lake area, but statements on the amount and direction of upstream ice transportation were generally missing or vague.

Modern analytical and field techniques

Characterization of the supracrustal rocks beyond the field and thin section observations (texture, mineralogy) hinges largely on major- and trace-element geochemical analysis. Detection limits, precision and accuracy of modern trace-element geochemical analytical techniques (i.e., the application of inductively coupled plasma–mass spectrometry [ICP-MS]) far exceed the quality of analyses used during previous geoscientific studies at Utik Lake (e.g., Milligan and Take, 1954; Weber, 1975; Bernier and MacLean, 1989). Geochemical analyses of rocks collected at Utik Lake in 2007 are still pending; nevertheless, the dominant mafic metavolcanic rocks are herein termed basalt, based on sparse existing whole-rock data (Milligan and Take, 1954; Bernier and MacLean, 1989) and field appearance.

Similarly, the present study incorporates isotope geochemical (Sm-Nd) and radiometric dating (e.g., U-Pb geochronology) not available or applied during previous studies. The new isotopic data will allow, in conjunction with geochemical and field data, direct comparison of the supracrustal rocks at Utik Lake with greenstone belts elsewhere in the northern Superior Province, and thus enable a tectonic analysis of the area.

During the 2007 field mapping, personal digital assistants (PDA) loaded with customized ArcPad® field data collection systems and Bluetooth-linked to GPS devices allowed the collection of all data digitally and in spatially integrated format on the outcrop. The new map data are being digitally combined and complemented with earlier mapping (Milligan and Take, 1954; Weber, 1974) in preparation for a final geological map, planned for release in 2008. The 1:25 000 scale preliminary geological map of Utik Lake (Böhm and Kremer, 2007) that is a companion release to this report summarizes the field data collected during five weeks of mapping in June and July of 2007.

Regional setting

On a regional scale, the Utik Lake greenstone belt lies along the northern margin of the Gods Lake Domain (Weber and Scoates, 1978), which is now referred to as the Oxford Lake–Stull Lake Terrane (Skulski et al., 2000) and is located south of the Pikwitonei Granulite Domain (Figure GS-10-1). The Utik Lake greenstone belt has a first-order east-west trend that parallels the regional structure of the Superior Province (Card, 1990) and is transposed along northeast-trending dextral shears, resulting in a dextral mega-boudin structure measuring approximately 30 km by 12 km (Figure GS-10-2). In the field, the megascopic structure is reflected at outcrop and smaller scales. Based on regional correlation using magnetic data and field lithological descriptions, the Bear Lake and Utik Lake greenstone belts likely form westerly continuations of the greenstone belts at Oxford and Knee lakes (Figure GS-10-1), which host a complex assemblage of supracrustal sequences partially unrelated in nature and age. At Knee Lake, three distinct but juxtaposed supracrustal sequences have been recognized (Gilbert, 1985; Syme et al., 1997, 1998, 1999): 1) the ca. 2.83 Ga, mafic metavolcanic–dominated Hayes River Group; 2) the <2.82 Ga but >2.78 Ga (Corkery et al., 2000), metasedimentary-dominated Opischikona sequence; and 3) the ca. 2.71 Ga, metasedimentary and bimodal metavolcanic Oxford Lake Group (Corkery et al., 2000).

Dating of the metavolcanic and metasedimentary rocks at Utik Lake is one of the main foci of this study and will, together with detailed major- and trace-element geochemistry and isotope geochemistry, facilitate correlation with the dated supracrustal rocks in the region. Based on comparison with results from 2006 investigations on the supracrustal rocks at Bear Lake (Böhm and Hartlaub, 2006; Hartlaub and Böhm, 2006), metavolcanic and metasedimentary rocks at Bear Lake are largely dissimilar in composition and may not be coeval with those at Utik Lake. Preliminary U-Pb zircon data for a felsic tuff from south-central Bear Lake indicate an age of 2716 ±2 Ma, interpreted as the formation age of the tuff (C. Böhm, unpublished isotope dilution–thermal ionization mass spectrometry data, 2007). This age supports the hypothesis that (part of) the supracrustal rocks at Bear Lake are contemporaneous and likely correlative with metavolcanic and metasedimentary rocks of the Oxford Lake Group.

Utik Lake greenstone belt

The Utik Lake greenstone belt represents a northeast- to east-trending supracrustal remnant that occupies much of the central and southern parts of Utik Lake (Figure GS-10-2) and extends semicontinuously along strike into Allbright Lake to the west, and Bigstone Lake–Knee Lake to the east (Figure GS-10-1). The Utik Lake greenstone belt is a homoclinal, south-facing sequence of mafic metavolcanic and volcanogenic metasedimentary rocks that underwent medium- to high-temperature and low-pressure (upper greenschist and amphibolite facies) regional metamorphism. Faulting and shearing strongly affected the belt margins and caused pinching out of the supracrustal rocks to the southwest and northeast, resulting in dextrally asymmetric,

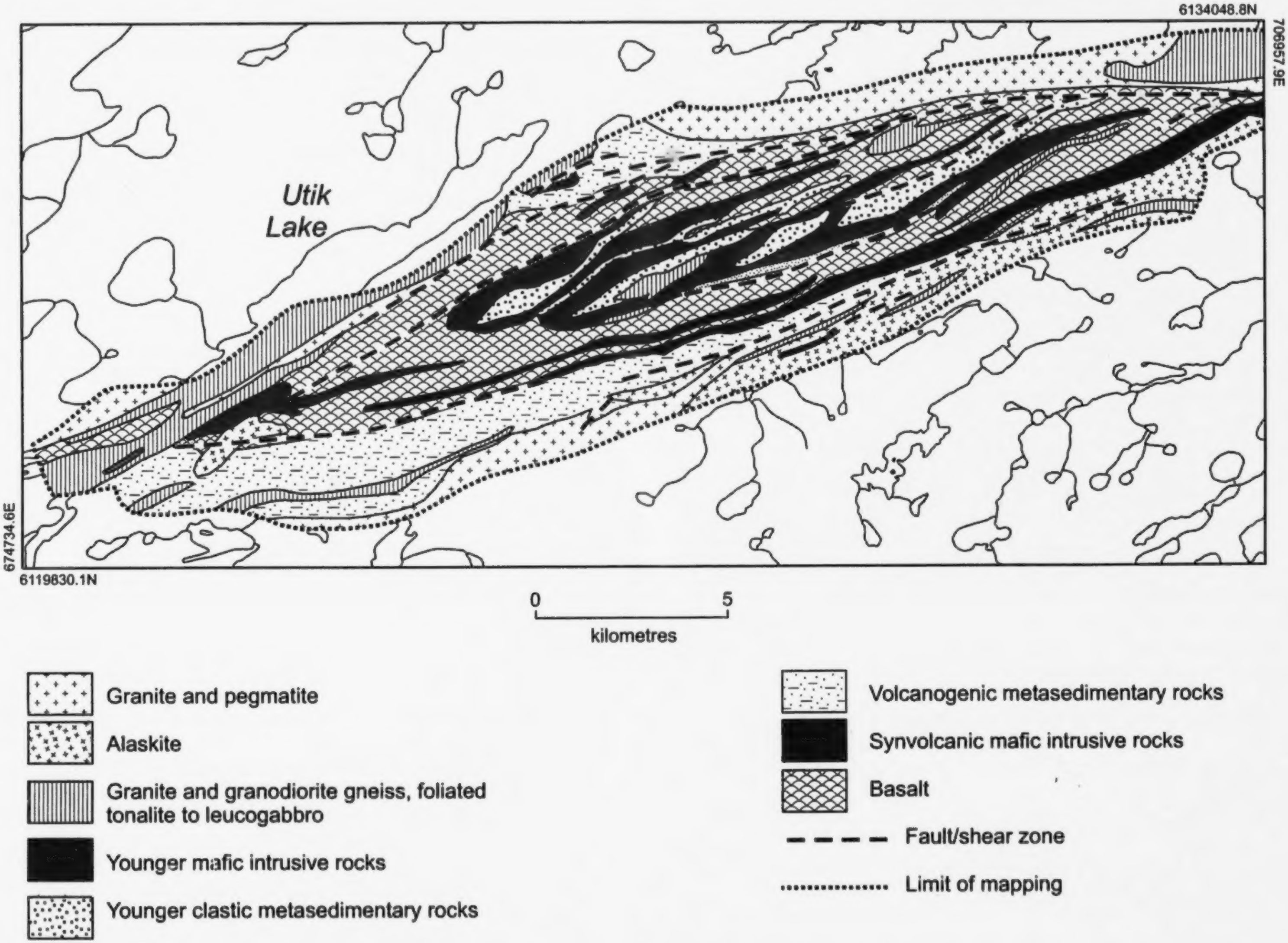
6134048.8N
706957.9E
Utik
Lake
674734.6E
6119830.1N
0
5
kilometres
Granite and pegmatite
Alaskite
Granite and granodiorite gneiss, foliated tonalite to leucogabbro
Younger mafic intrusive rocks
Younger clastic metasedimentary rocks
Volcanogenic metasedimentary rocks
Synvolcanic mafic intrusive rocks
Basalt
Fault/shear zone
Limit of mapping

Figure GS-10-2: *Schematic bedrock geology of the Utik Lake greenstone belt* (simplified from *Böhm and Kremer, 2007*).

large-scale deformation of the belt at Utik Lake (Figures GS-10-1, -2). Compared to the highly strained greenstone belt margins, primary volcanic and sedimentary structures important for identifying the detailed lithostratigraphy and architecture are well preserved in internal portions of the belt.

The supracrustal sequence at Utik Lake is subdivided into a number of 'panels', composed of pillowed and massive basalt, and associated diabase and gabbro. The panels are internally stratigraphically coherent and differ in, for example, the proportion and type of basalt or the abundance of metasedimentary rocks. Contacts between panels are typically covered (by the long easterly-trending channels that characterize Utik Lake) and may be stratigraphic, structural or a combination of both.

Panels composed of mafic rocks are separated by conformable metasedimentary rock sequences comprising banded iron formation, greywacke siltstone to mudstone turbidite, and conglomerate. These metasedimentary rocks are interpreted to represent two distinct sequences: 1) those derived from and coeval with intercalated mafic metavolcanic and intrusive rocks, and 2) a younger clastic sequence whose source was different and distinct from the underlying mafic-dominated supracrustal rocks. The metavolcanic rocks and all metasedimentary rocks were intruded by a suite of diabase and gabbro dikes and sills, and the greenstone belt was subsequently invaded and enclosed by several generations of granitoid rocks.

The main rock types at Utik Lake, as outlined on the 1:25 000 scale geological map (Böhm and Kremer, 2007), are schematically summarized in Figure GS-10-3 and their distribution delineated in Figure GS-10-2.

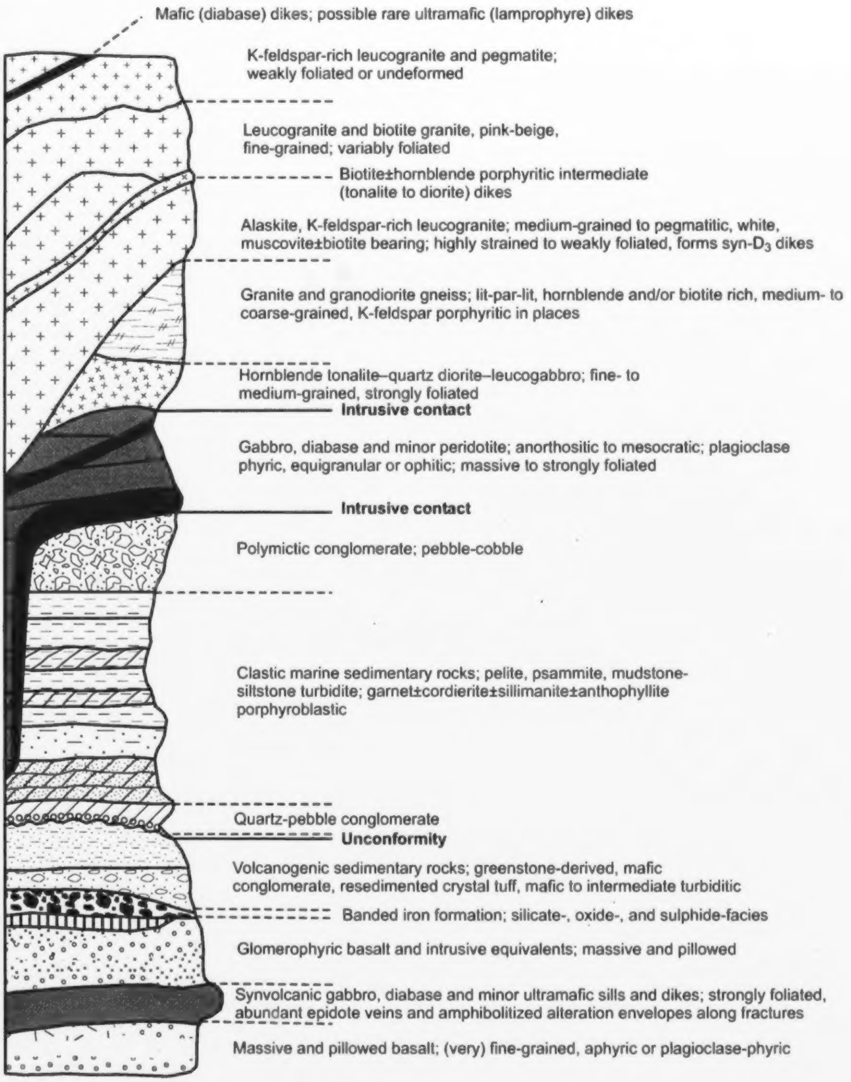
Mafic (diabase) dikes; possible rare ultramafic (lamprophyre) dikes
K-feldspar-rich leucogranite and pegmatite; weakly foliated or undeformed
Leucogranite and biotite granite, pink-beige, fine-grained; variably foliated
Biotite±hornblende porphyritic intermediate (tonalite to diorite) dikes
Alaskite, K-feldspar-rich leucogranite; medium-grained to pegmatitic, white, muscovite±biotite bearing; highly strained to weakly foliated, forms syn-D$_3$ dikes
Granite and granodiorite gneiss; lit-par-lit, hornblende and/or biotite rich, medium- to coarse-grained, K-feldspar porphyritic in places
Hornblende tonalite–quartz diorite–leucogabbro; fine- to medium-grained, strongly foliated
Intrusive contact
Gabbro, diabase and minor peridotite; anorthositic to mesocratic; plagioclase phyric, equigranular or ophitic; massive to strongly foliated
Intrusive contact
Polymictic conglomerate; pebble-cobble
Clastic marine sedimentary rocks; pelite, psammite, mudstone-siltstone turbidite; garnet±cordierite±sillimanite±anthophyllite porphyroblastic
Quartz-pebble conglomerate
Unconformity
Volcanogenic sedimentary rocks; greenstone-derived, mafic conglomerate, resedimented crystal tuff, mafic to intermediate turbiditic
Banded iron formation; silicate-, oxide-, and sulphide-facies
Glomerophyric basalt and intrusive equivalents; massive and pillowed
Synvolcanic gabbro, diabase and minor ultramafic sills and dikes; strongly foliated, abundant epidote veins and amphibolitized alteration envelopes along fractures
Massive and pillowed basalt; (very) fine-grained, aphyric or plagioclase-phyric

Figure GS-10-3: *Schematic lithostratigraphy of the Utik Lake greenstone belt and bounding intrusive terranes.*

Basalt

The mainly mafic metavolcanic flows (tholeiitic normal mid-ocean-ridge basalt [N-MORB]; Bernier and MacLean, 1989) at southwestern Utik Lake have been described in detail by Weber (1974) and Hargreaves and Ayres (1979). These authors focused on the large island in southwestern Utik Lake (Mistuhe Island), where the well-exposed basalt flows are predominantly massive in the central and southern parts of the island but largely pillowed along its northern shore, particularly towards the east. The focus of these previous studies was to document detailed flow stratigraphy, morphology and primary volcanic processes. In comparison, the present mapping focuses on a more regional approach, to better constrain the variations in texture, composition and extent of the several metavolcanic panels of the belt. Common characteristics used to describe and subdivide the basaltic sequences include colour and texture, amount and size of plagioclase phenocrysts and/or glomerocrysts, amount of amygdules and/or spherulites, thickness of selvages, pillow sizes, and amount and composition of interpillow hyaloclastite and/or interpillow sediment and peperite.

All observed basaltic flow sequences and interlayered or intercalated metasedimentary rocks are consistently southward facing, resulting in one homoclinal supracrustal sequence. Facing direction criteria in pillow basalt include pillow shape, pillow shelves and eyebrow structures, and amygdule concentration.

As indicated by previous mapping (Milligan and Take, 1954; Weber, 1974), the basaltic sequences at Utik Lake can be subdivided into several 'panels' that possibly represent individual pulses of volcanic activity and, in some cases, are separated by metasedimentary rocks or shear zones. At a first level, the basalt flows are subdivided into an older, northwestern panel that is separated from a southern panel of basaltic and associated mafic igneous rocks by a continuous central sequence of metasedimentary rocks and younger intrusions up to 2 km wide (Figure GS-10-2). The northwestern panel is best preserved in exposures in north-central Utik Lake (e.g., UTM Zone 14, 688317E, 6128877N [NAD83]), where aphyric and nonamygdaloidal basalt is characterized by large (up to few metres long) and irregularly shaped, closely packed pillows that are devoid of shelves, have thick selvages (up to 3 cm) and little (≤5%) interpillow material (Figure GS-10-4a). To the southeast, variably plagioclase-phyric and/or glomerocrystic (up to 1.5 cm; Figure GS-10-4b), amygdaloidal pillow basalt represents part of a separate metavolcanic panel. Along the southern margin of this flow panel, the basalt is highly strained with strongly flattened pillows, suggesting that the panel is, at least in part, bounded by a shear zone.

In comparison, the much thicker and more extensive southern panel has generally smaller pillows (up to ~1.5 m, averaging a few decimetres) and can be internally subdivided into the following subunits (from northwest to southeast): 1) aphyric nonamygdaloidal basalt with thin selvages and minor interpillow material (Figure GS-10-4c); 2) quartz-feldspar amygdaloidal basalt with thick selvages (~2 cm) and abundant (up to 20%) interpillow material (epidote-plagioclase-quartz±carbonate ±amphibole); 3) aphyric basalt with thick selvages and containing little interpillow material; and 4) a major panel of variably plagioclase-phyric (up to ~3 cm) basalt, up to several kilometres wide, that is well exposed on Mistuhe Island (Figure GS-10-4d).

Complete flows are, in some instances, exposed in the southernmost panel of basalt. Typical flow thickness is approximately 15–20 m, which is comparable to the 10–35 m flow thicknesses observed by Hargreaves (1975). An excellent exposure of a complete flow, located along the northwest shore of Mistuhe Island, is illustrated in Figure GS-10-5. The following schematic succession of internal flow structures was observed in a number of instances (from flow base to top):

- up to a few metres of pillowed basalt, grading into pillowed and massive basalt (Figure GS-10-5a)
- a central zone of up to 15 m of massive basalt, variably fractured
- up to 5 m of brecciated basalt (Figure GS-10-5b, -5c) and flow-top breccia (Figure GS-10-5d), with injections of massive basalt from the central zone; variably altered due to high porosity

Commonly, outcrops that are several metres to tens of metres in size are composed entirely of either pillowed or massive basalt, and flow contacts were not observed or not exposed. These relationships suggest that thick, laterally continuous pillow and massive flow units are intercalated. Locally the flows are separated by chert (Figure GS-10-6a), banded iron formation (Figure GS-10-6b), and/or shale/mudstone turbidite, presumably deposited during periods of relative volcanic quiescence.

The basalt is commonly altered, which can assume a variety of expressions: 1) primary, seafloor hydrothermal alteration (Figure GS-10-6c); and 2) secondary, tectonometamorphic–related, pervasive, patchy and fracture-, vein- or shear-controlled alteration, such as epidotization, silicification (Figure GS-10-6d) and sulphidization. At a few localities on southwestern Utik Lake, a special type of primary volcanogenic alteration is developed in and adjacent to structures interpreted as fumarolic pipes (Bernier and MacLean, 1989).

Alteration pipes

Volcanogenic hydrothermal alteration and gold-bearing chert were first noted on Mistuhe Island in southwestern Utik Lake by Weber (1974) and subsequently studied in detail by Bernier and MacLean (1989). Comparable to 'black smokers' at mid-ocean ridges of the modern seafloor, alteration pipes in basalt at southwestern Utik Lake produced pervasive magnesian, iron and silica alteration in the host basalt and sulphidization along

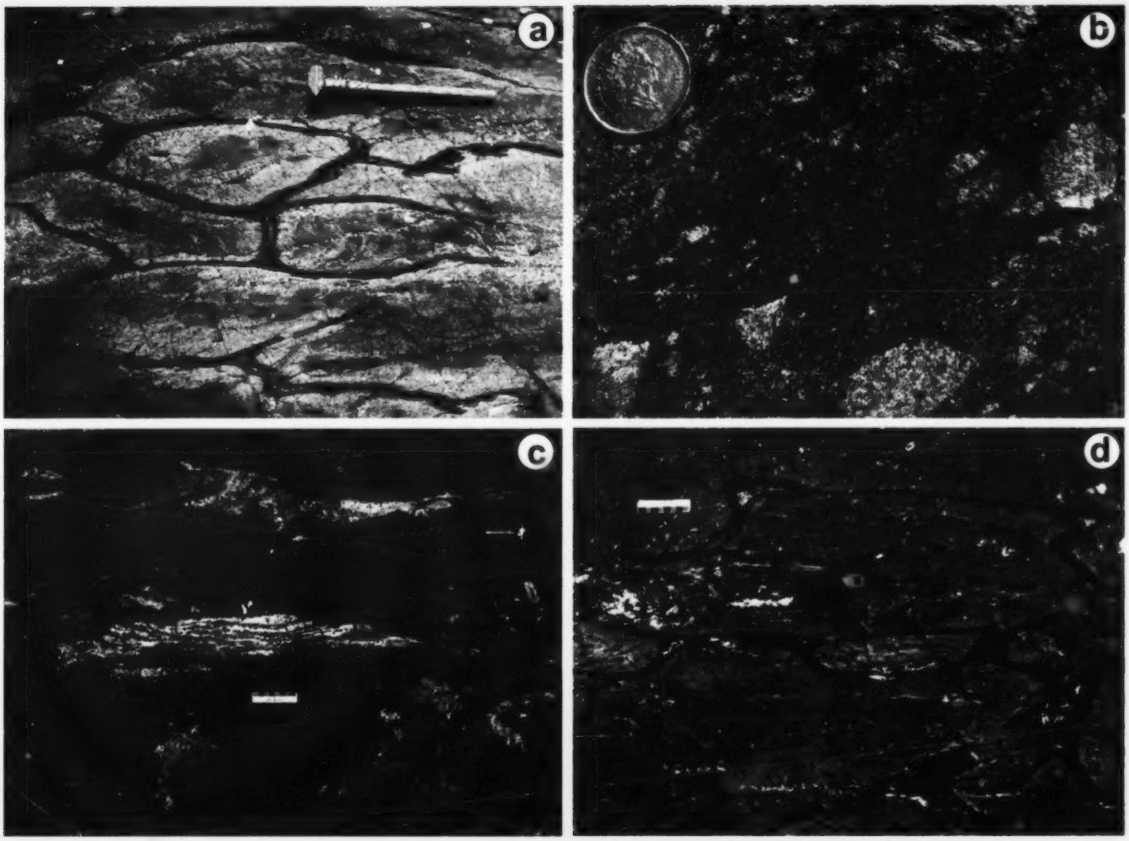

Figure GS-10-4: *Outcrop photos of basalt flows from the Utik Lake greenstone belt:* ***a)*** *aphyric, nonamygdaloidal pillowed basalt with thick selvages and little interpillow material, north-central Utik Lake (UTM Zone 14, 688356E, 6128820N [NAD83]);* ***b)*** *plagioclase-phyric and glomerocrystic basalt (coin is 2 cm in diameter), northeastern Utik Lake (UTM Zone 15, 315211E, 6130103N);* ***c)*** *pillow shelves in aphyric basalt, central Utik Lake (top is up [=south] in photo; UTM Zone 15, 315488E, 6128145N);* ***d)*** *flattened, plagioclase-phyric pillowed basalt, south shore of Mistuhe Island, southern Utik Lake (UTM Zone 14, 688488E, 6124585N).*

synvolcanic veins and fractures. Major alteration pipes (e.g., 'pipes 1 and 2' in Bernier and MacLean, 1989) are up to 2 m wide, extend downsection for at least 20 m in variably plagioclase-phyric and glomeroporphyritic pillowed and massive tholeiitic basalt, and are oriented dominantly subvertical to the flow contact (Figure GS-10-7a). The alteration pipes are the exhalitive source for chemical sediments (mixed with detritus) that are prominently preserved as continuous chert-magnetite banded iron formation up to 4 m thick, as well as discontinuous auriferous sulphide-bearing chert locally interbedded with graphitic argillite (Bernier and MacLean, 1989). The latter unit may be similar to up to 2 m of siliceous grey sediment observed between the flow top and the iron formation (Figure GS-10-7b). Where transected by alteration pipes, basalt is commonly altered to a fine-grained, greenish white, bleached- to rusty-weathering material. The flow top and immediate wallrock exhibit the highest degrees of alteration and metasomatism along contact zones, up to a few decimetres wide, that contain abundant garnet±andalusite±anthophyllite±cordierite porphyroblasts, suggesting that they were recrystallized under lower amphibolite-facies conditions (550°C and 2.5 kbar; Bernier and MacLean, 1989).

The chemical and clastic metasedimentary rocks that were deposited directly on the basalt flow surface at southwestern Utik Lake represent a unique example of a Mesoarchean ocean-floor environment that hosts an alteration system similar to that in Noranda-type massive-sulphide deposits (e.g., Morton and Franklin, 1987), whereas the trace-metal association in the auriferous chert (Bernier and MacLean, 1989) is similar to that in modern seafloor hydrothermal environments (e.g., Hannington et al., 1986). In addition, the Utik Lake example may be an analogue to the well-documented volcano-hydrothermal Black Chert Member (massive and laminated black chert, siliceous shale, tuffaceous chert) of the ca. 3.2 Ga Cleaverville Group of the coastal Pilbara terrane, northwestern Australia, which hosts possible microbial material (Kiyokawa et al., 2006).

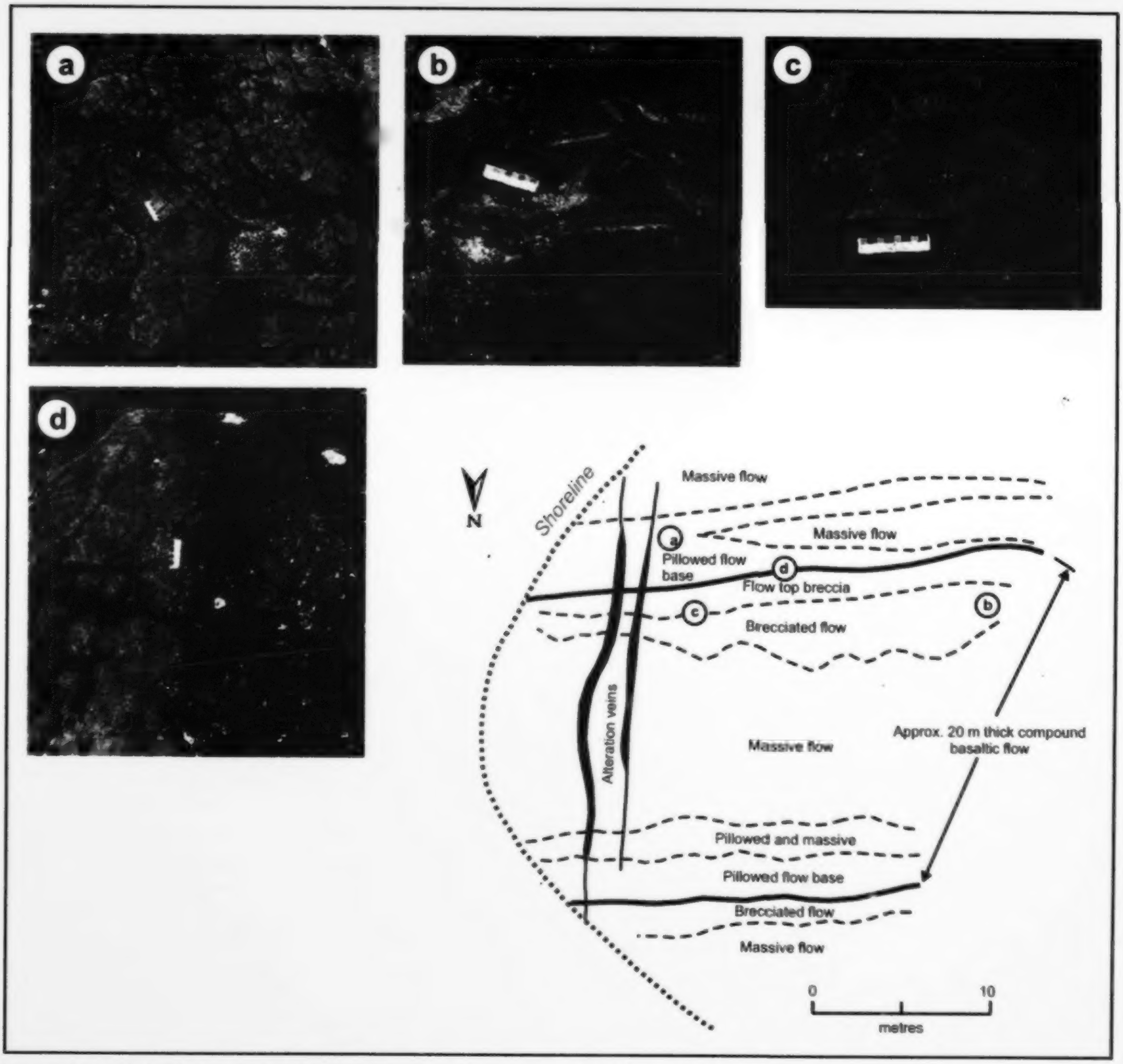
a
b
c
d
N
Shoreline
Massive flow
Massive flow
Pillowed flow base
Flow top breccia
Brecciated flow
Alteration veins
Massive flow
Approx. 20 m thick compound basaltic flow
Pillowed and massive
Pillowed flow base
Brecciated flow
Massive flow
0
10
metres

***Figure GS-10-5:** Outcrop sketch of well-exposed and preserved basaltic flow sequence, northwest shore of Mistuhe Island, southwestern Utik Lake (UTM Zone 14, 689365E, 6125626N [NAD 83]). Outcrop photograph inserts are: **a)** pillowed basalt grading into massive basalt (upper right); **b)** brecciated pillowed basalt flow; **c)** brecciated flow with sediment-filled cavities produced by sediment-flow interaction (peperite); and **d)** flow-top breccia (right), with base of pillowed basalt flow at left (photo facing west).*

Synvolcanic, mafic intrusive rocks

Based on field relationships, mafic intrusive rocks in the Utik Lake greenstone belt can be subdivided into two main groups: 1) gabbro and diabase sills and dikes that are comagmatic with basalt flows; and 2) a younger suite of diabase, gabbro and minor pyroxenite that forms intrusive bodies in, and carries xenoliths of, marine clastic metasedimentary rocks (*see* below).

Gabbro and diabase form sills and dikes in basalt that range in thickness from a few decimetres to several hundred metres (Figure GS-10-2). The bulk compositions of basalt, gabbro and diabase are similar and suggest a comagmatic relationship. In addition, primary hydrothermal alteration pipes are developed in both the mafic flows and the intrusions, where they are present together. Diabase dikes were observed to form feeders into basalt flows, whereas major mafic intrusive bodies are predominantly differentiated gabbroic sills, such as those exposed on central Mistuhe Island. Fine-grained gabbro and diabase intruded into basalt flows are commonly equigranular to weakly ophitic, and can be locally difficult to distinguish from aphyric, massive, medium- to coarse-grained basalt. As a consequence, the proportion of mafic intrusive versus mafic massive flow units cannot be readily determined. Detailed studies focusing on basalt flow morphology at southwestern Utik Lake show that

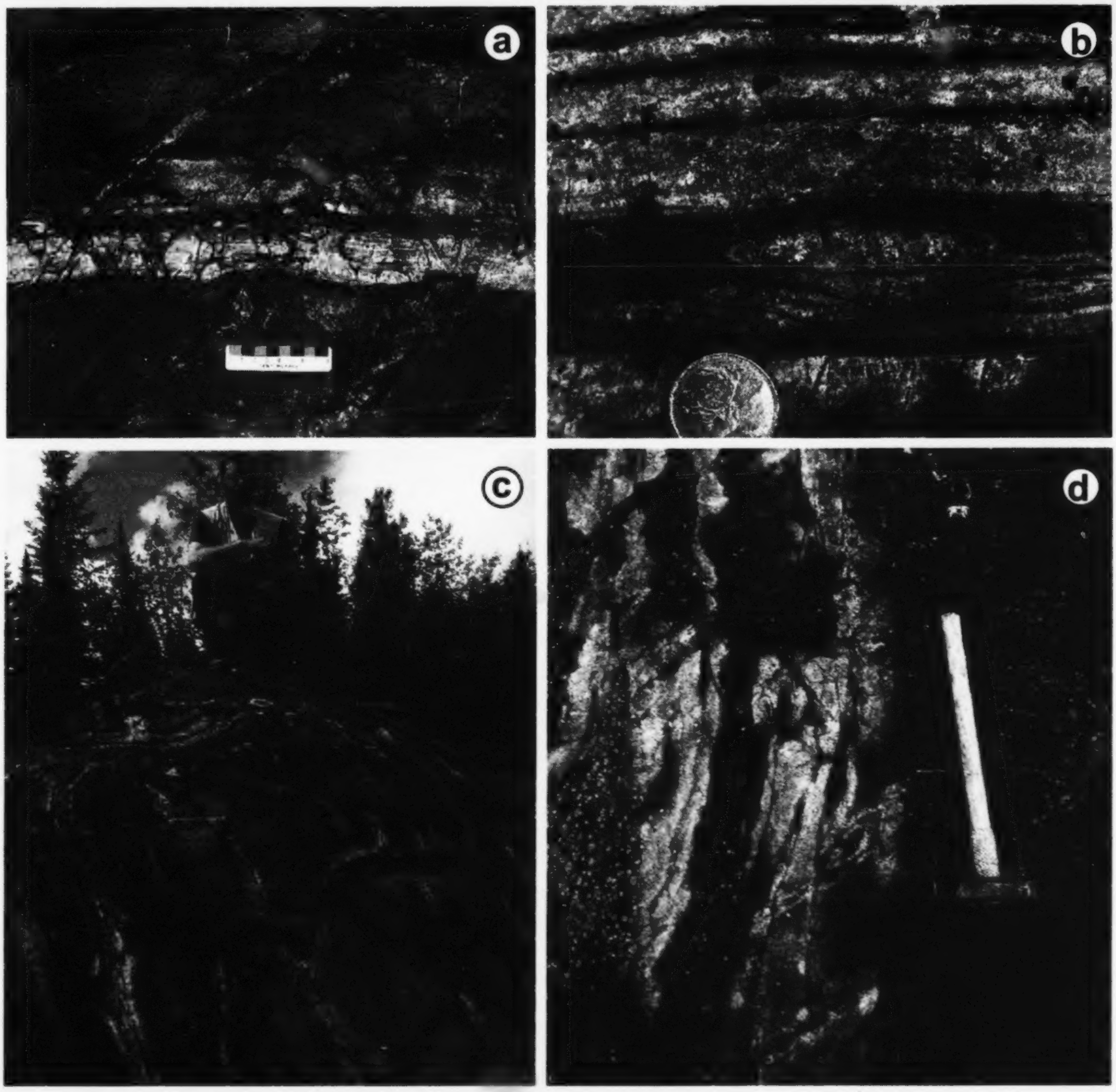

Figure GS-10-6: *Outcrop photos of basaltic, associated chemical sedimentary and altered rocks:* ***a)*** *chert interlayer in basalt, north-central Utik Lake (UTM Zone 14, 687830E, 6128124N [NAD83]);* ***b)*** *silicate-oxide–facies banded iron formation along south shore of Mistuhe Island, southwestern Utik Lake (UTM Zone 14, 687297E, 6124301N);* ***c)*** *amphibolitized alteration envelopes along polygonal fractures in gabbro that mimic 'pseudopillows', southwestern Utik Lake (UTM Zone 14, 689214E, 6124939N); and* ***d)*** *concordant silicification in basalt, Mistuhe Island, southwestern Utik Lake (UTM Zone 14, 688034E, 6124710N).*

massive flows make up more than half of the entire mafic flow sequence (Hargreaves and Ayres, 1979, Table 1 and Figure 3). Massive and pillowed flows are commonly interlayered, and massive flows can laterally grade into pillowed flows, which makes mapping of pillowed versus massive flows unfeasible at a regional scale.

Volcanogenic metasedimentary rocks

Metasedimentary rocks associated with the Utik Lake mafic metavolcanic formations are commonly derived from intermediate to mafic volcanic rocks, and include conglomeratic, tuffaceous and turbiditic members. Volcanic conglomerate is clast to matrix supported and composed of subrounded pebble- to cobble-sized (up to ~15 cm) clasts of andesitic to basaltic composition in a silty to sandy matrix of similar composition (Figure GS-10-8a). Mafic conglomerate lies conformably on, or in sheared contact within, basalt (Figure GS-10-8b) and, in some localities, together with silicate±sulphide iron formation. One exposure on southwestern Utik Lake (UTM Zone 14, 686996E, 6124234N) shows basalt and mafic conglomerate in a conformable contact relationship.

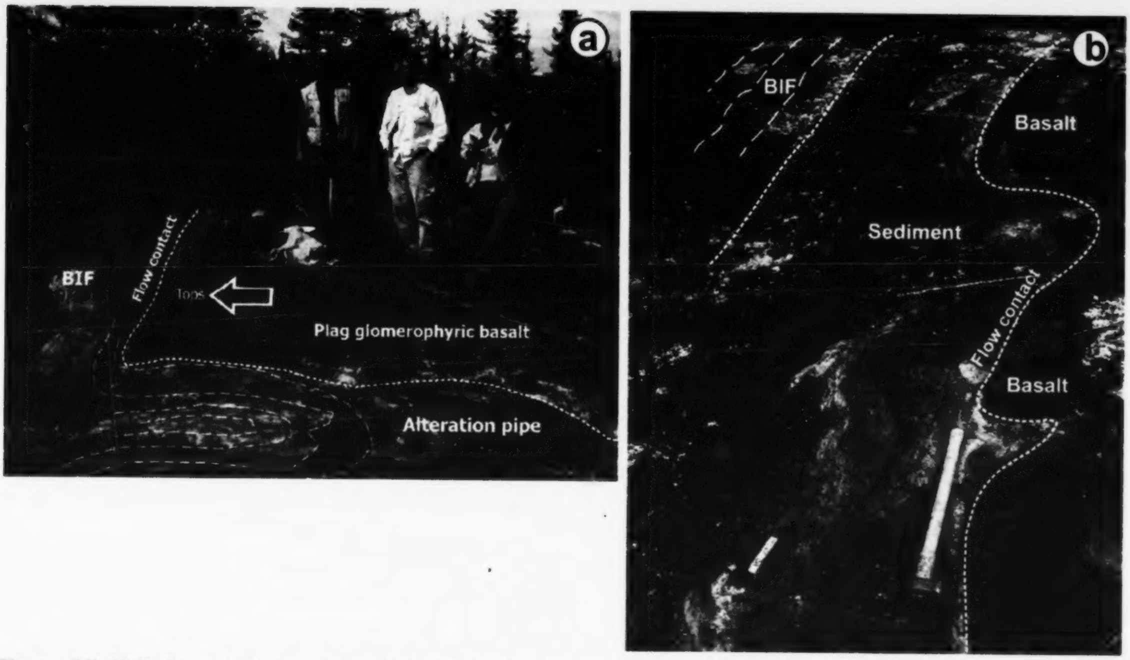

Figure GS-10-7: Outcrop photographs of alteration pipes in basalt and associated banded iron formation and metasedimentary rocks on Mistuhe Island, southwestern Utik Lake (UTM Zone 14, 688132E, 6124706N [NAD83]): ***a)*** *alteration 'pipe 1' of Bernier and MacLean (1989), with banded iron formation (BIF) draping into the pipe;* ***b)*** *siliceous sediment between basalt flow top (right) and banded iron formation (upper left), approximately 100 m west and along strike of iron formation at 'pipe 1' location (photo facing west).*

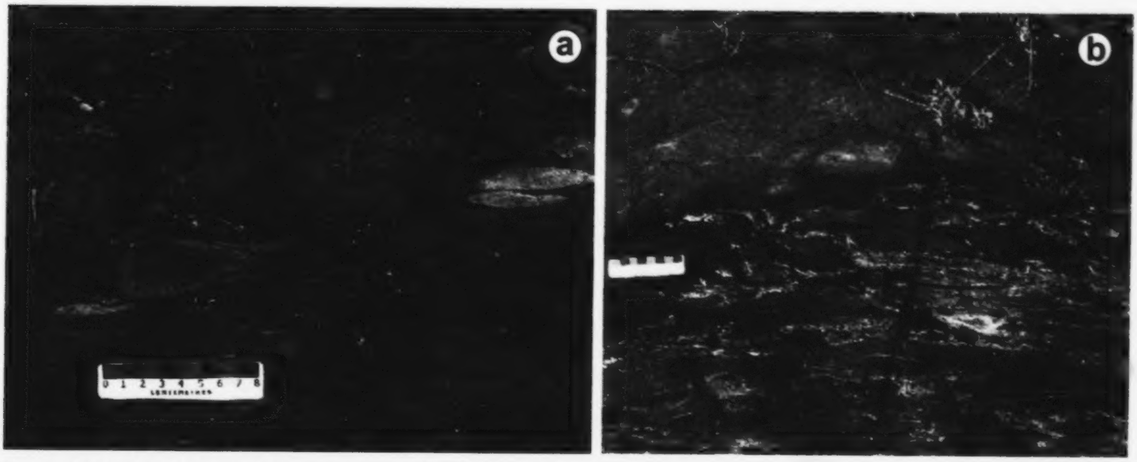

Figure GS-10-8: Outcrop photographs of volcanic-derived metasedimentary rocks, southwestern Utik Lake: ***a)*** *strongly foliated, clast-supported, dominantly mafic volcanic conglomerate with few intermediate and felsic intrusive clasts (UTM Zone 14, 686043E, 6123978N [NAD83]);* ***b)*** *conformable contact between foliated and sheared basalt (top) and mafic conglomerate (bottom UTM Zone 14, 686996E, 6124234N).*

In an adjacent exposure to the east (UTM Zone 14, 688920E, 6124720N), the basalt is highly strained, altered and associated with locally sulphidized and garnet-rich conglomeratic and mudstone-siltstone turbiditic wacke.

Younger clastic metasedimentary rocks

A younger suite of fluvial-alluvial and marine clastic metasedimentary rocks lies in sheared, likely unconformable contact on the mafic metavolcanic rocks and associated volcanogenic metasedimentary rocks. The earlier supracrustal assemblage was likely tilted, deformed and eroded prior to deposition of the younger clastic metasedimentary rocks in synclinal structural basins between the metavolcanic panels. The metasedimentary sequence

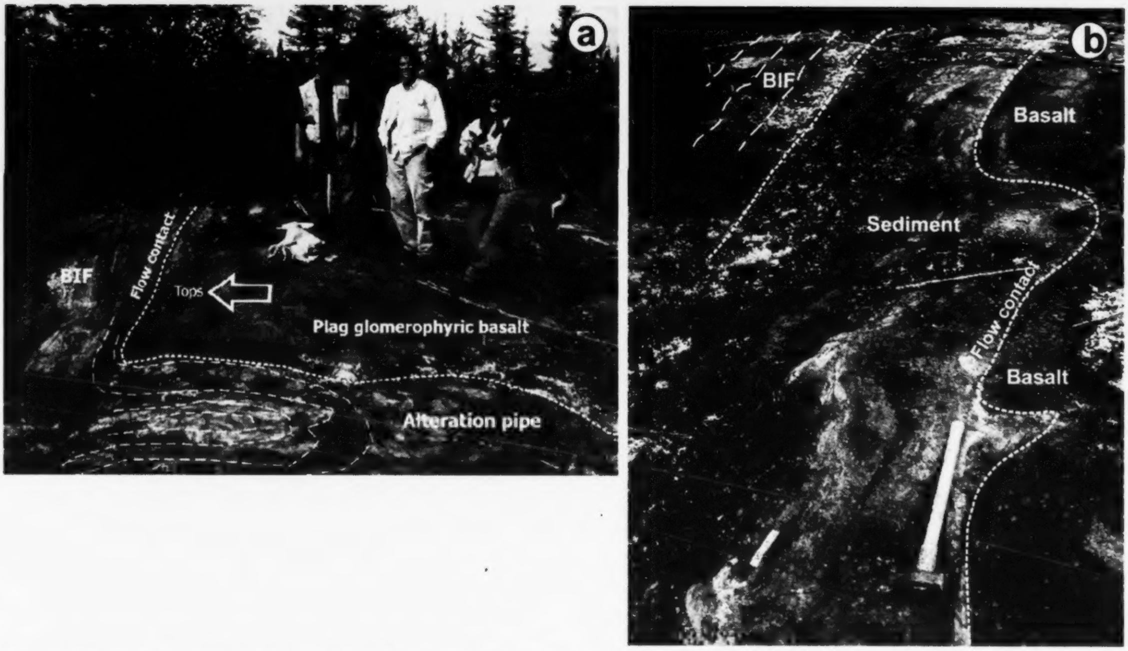

Figure GS-10-7: *Outcrop photographs of alteration pipes in basalt and associated banded iron formation and metasedimentary rocks on Mistuhe Island, southwestern Utik Lake (UTM Zone 14, 688132E, 6124706N [NAD83]):* ***a)*** *alteration 'pipe 1' of Bernier and MacLean (1989), with banded iron formation (BIF) draping into the pipe;* ***b)*** *siliceous sediment between basalt flow top (right) and banded iron formation (upper left), approximately 100 m west and along strike of iron formation at 'pipe 1' location (photo facing west).*

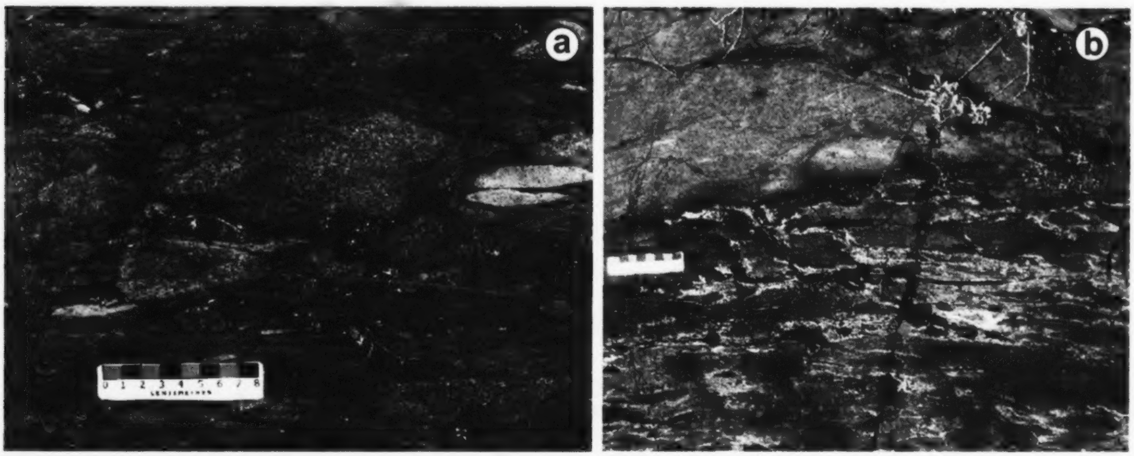

Figure GS-10-8: *Outcrop photographs of volcanic-derived metasedimentary rocks, southwestern Utik Lake:* ***a)*** *strongly foliated, clast-supported, dominantly mafic volcanic conglomerate with few intermediate and felsic intrusive clasts (UTM Zone 14, 686043E, 6123978N [NAD83]);* ***b)*** *conformable contact between foliated and sheared basalt (top) and mafic conglomerate (bottom UTM Zone 14, 686996E, 6124234N).*

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Younger clastic metasedimentary rocks

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The Opischikona Narrows metasedimentary succession exposed on south-central Knee Lake consists of greywacke, pebbly sandstone and conglomerate; these lie in a synclinal structural basin unconformably on Hayes River Group basalt (Syme et al., 1998). Based on their tectonic position and nature, the younger clastic metasedimentary rocks at Utik Lake may be correlative with the Opischikona succession. Age constraints on the Opischikona rocks are preliminary but confirm sedimentation younger than the ca. 2.83 Ga Hayes River Group supracrustal rocks (Corkery et al., 2000); the youngest dated detrital zircon in sandstone yielded a maximum sediment age of ca. 2822 Ma, and a feldspar-porphyry sill emplaced into the metasedimentary rocks is ca. 2783 Ma. Alternatively, the clastic metasedimentary rocks at Utik Lake could be related to the ca. 2.70–2.71 Ga Oxford Lake Group (Corkery et al., 2000), which also contains conglomerate, pebbly greywacke and sandstone-siltstone turbiditic wacke, and is fault bounded within the Hayes River Group metavolcanic rocks at Knee Lake (Syme et al., 1998).

At Utik Lake, conglomerate and pelitic to psammitic wacke are the dominant metasedimentary rocks. In addition to the mafic volcanic–derived conglomerate described above, more than one generation of conglomerate likely exists within the younger metasedimentary sequence. A variably sulphidic quartz-pebble conglomerate (Figure GS-10-9a) forms the base of the younger sedimentary sequence and is interlayered with and/or

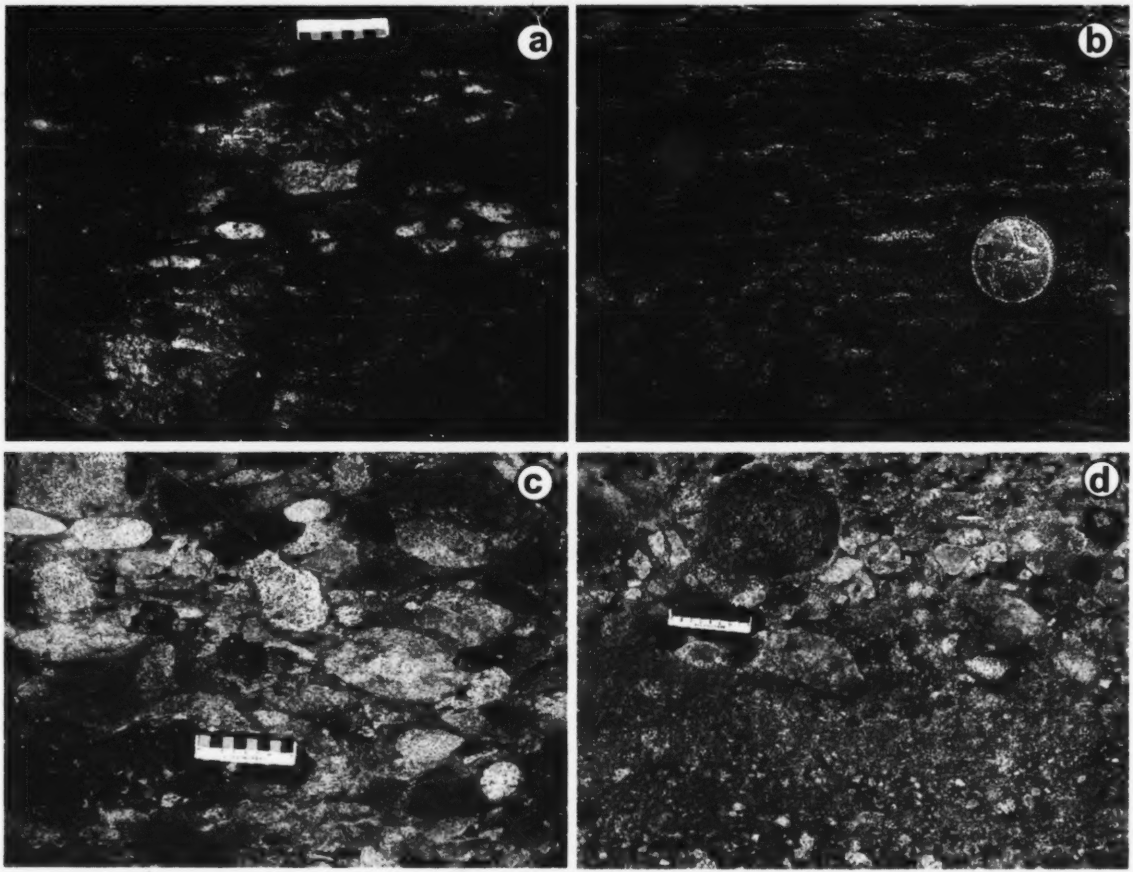

***Figure GS-10-9:** Outcrop photographs of clastic metasedimentary rocks, Utik Lake: **a)** foliated and rodded, clast-supported gossanous conglomerate with dominantly quartz, chert iron formation and lesser mafic volcanic clasts (UTM Zone 14, 690752E, 6129020N [NAD83]); **b)** fine, foliation- and layering-parallel, sillimanite-quartz–rich lamellae in partially pinitized cordierite porphyroblasts in pelitic greywacke (UTM Zone 15, 315854E, 6128380N); **c)** polymictic conglomerate with quartz, chert iron formation, gabbro, hornblende tonalite, mafic metavolcanic and psammitic clasts (UTM Zone 14, 687526E, 6126645N); **d)** scour channel of polymictic conglomerate bed into pebbly greywacke, stratigraphic top to the south (UTM Zone 14, 689775E, 6127977N).*

grades into greywacke, where exposed in direct contact with the underlying mafic metavolcanic rocks and volcanic metasedimentary rocks.

Layered greywacke gneiss, ranging from pelite-semipelite to interlayered psammite, is most voluminous and best exposed in the northernmost part of the Utik Lake greenstone belt (e.g., UTM Zone 14, 688625E, 6129308N), where locally intense cordierite, garnet±sillimanite-quartz (faserkiesel)±anthophyllite blastesis indicates metamorphism at temperatures in excess of 600°C (sillimanite Barrovian zone, as defined in Bucher and Frey, 1994). Alternating garnet- and cordierite-rich porphyroblastic layers likely reflect primary compositional layering, except where garnet-rich zones form around intermediate to mafic lenses (amphibolite) or where related to iron-silica–rich fluids permeating along veins and fractures in metasedimentary rocks. The fact that the pelitic to psammitic turbiditic metasedimentary rocks are locally interlayered with and grade into conglomeratic beds indicates that the sequence was likely deposited in a shallow-marine shelf environment.

In the central parts of Utik Lake, abundant layered intermediate to felsic greywacke has a peculiar, knotty to coarse porphyroblastic texture (Figure GS-10-9b). This unit was described by previous workers (Milligan and Take, 1954; Weber, 1974) as 'cordierite schist'. The authors' interpretation is that these layered rocks represent magnesium-iron–rich peraluminous pelitic rocks that were originally mudstone and shale. Their largely intermediate composition (*see* major element compositions in Milligan and Take, 1954, p. 45) may reflect (partial) derivation from the underlying mafic metavolcanic and intrusive rocks.

Polymictic conglomerate forms extensive and semi-continuous exposures at several localities on Utik Lake, with the best examples along the north shore of the southernmost lake channel and in the central portion of the lake (e.g., UTM Zone 14, 689775E, 6127977N; Figure GS-10-9c). The polymictic conglomerate is clast supported and poorly sorted, with clasts and cobbles up to approximately 30 cm. Rare large cobbles are leucocratic felsic intrusive rock and minor altered gabbro to pyroxenite, whereas medium- to smaller sized (a few centimetres) clasts range in composition from abundant (vein) quartz to lesser mafic metavolcanic rocks (amphibolite), psammitic rocks, and sulphidic chert and banded iron formation (Figure GS-10-9a). Better sorted, pebbly, matrix-supported interlayers have a grey psammitic groundmass similar to the matrix of the coarse clastic conglomerate. Greywacke and psammite interbeds are up to a few decimetres thick and display locally well-preserved trough crossbedding and fining-upward graded bedding that, together with local scour channels of conglomerate into greywacke mudstone (Figure GS-10-9d), define southward younging of the subvertically tilted metasedimentary package. The polymictic clast composition of the conglomerate and its contained bedforms suggest deposition in a fluvial-alluvial environment, representing continental erosion of a terrane that is at least partially exotic compared to the underlying mafic-dominated rocks preserved at Utik Lake.

Younger mafic intrusive rocks

The younger suite of mafic intrusive rocks, consisting of gabbro, diabase and minor pyroxenite, forms bodies up to several kilometres in size in the older mafic metavolcanic and metasedimentary rocks. The mafic intrusions are typically massive and only weakly to moderately foliated along the margins or in higher strain zones. Texture in medium- to coarse-grained gabbro is equigranular, ophitic, clotted or porphyritic, and locally pegmatitic, with leucocratic to mesocratic compositions (~20–70% plagioclase). Diabase is fine to coarse grained and ophitic, with plagioclase laths up to a few millimetres long. It can be equigranular or pyroxene±amphibole porphyritic. The mafic intrusions are generally nonmagnetic and homogeneous, and show gradual variations in grain size and/or composition. Within the central and southeastern mafic intrusions (Figure GS-10-2), coarse-grained melanocratic gabbro to pyroxenite appears to be enclosed or intruded by gabbro and diabase; however, at other locations, the contact between layered gabbro and pyroxenite is layer parallel and may be comagmatic (e.g., UTM Zone 15, 310748E, 6128137N).

Felsic intrusive rocks at Utik Lake

Although not a primary interest of this study, felsic intrusive rocks within and immediately to the north and south of the Utik Lake greenstone belt have been included in the present mapping (Figure GS-10-2) in order to study the greenstone belt evolution in context with the younger granite terranes. Based on combined field observations, all mapped felsic intrusive rocks at Utik Lake are interpreted to be younger than, and therefore intrusive into, the mafic intrusive and supracrustal rocks. Apart from the presence of smaller pegmatite and porphyry dikes, which increase in abundance toward both belt margins, the granitoid terranes north and south of the Utik Lake greenstone belt differ significantly in nature and composition.

To the north, the greenstone belt is flanked by a relatively homogeneous suite of pink to beige, leucocratic, variably K-feldspar–porphyritic, biotite-bearing granodiorite and granite with K-feldspar–rich pegmatite patches and dikes. These granitic rocks are generally massive to weakly foliated, but locally developed a stronger foliation close to the presumably structurally modified contact with the supracrustal rocks. In the northwest corner of the map area, where 060°–070° and 090° fabrics join, strongly foliated hornblende±biotite–rich tonalite and granodiorite appear to be cut by leucogranite.

Along the southern margin of the greenstone belt, alaskite is the predominant intrusive phase and appears to have been preferentially emplaced along the southern belt margin, where it is locally highly strained and sheared (protomylonite; Figure GS-10-10a, -10b). Intrusions of alaskite (graphic-textured K-feldspar-quartz–rich granite) weather characteristically light grey to white, are pegmatitic in places and contain up to 15% muscovite±biotite±garnet.

In addition to variable amounts of alaskite, a complex suite of relatively older, intermediate to felsic intrusive rocks outcrops along the south shore of Utik Lake. They bound the supracrustal belt and include granite to granodiorite gneiss, *lit-par-lit* S-type orthogneiss, hornblende- and/or biotite-rich granodiorite, which is locally K-feldspar porphyritic, and fine- to medium-grained, strongly foliated hornblende tonalite to quartz diorite and leucogabbro. This orthogneiss was described by Milligan (1952) as "grey gneissic granite" and occupies much of the area between Utik and Bear lakes. Its age is uncertain but relatively constrained by xenoliths of older gabbro and greywacke (maximum age) and by alaskite injection (minimum age). Preliminary U-Pb zircon data from a possibly related granite that is intrusive into the basalt at north Bear Lake (Hartlaub and Böhm, 2006) yielded an emplacement age of ca. 2.70 Ga (unpublished multicollector laser-ablation ICP-MS data, 2007).

Lit-par-lit gneiss along the south shore of Utik Lake likely formed by injection of granitic melt into the metamorphosed supracrustal rocks, prior to high-strain overprint that transposed the rocks into gneiss. Within the gneiss, medium to coarse porphyritic hornblende±biotite granodiorite and granite form structurally discontinuous transposed bodies. The compositional and structural complexities, particularly along the southwest shore of Utik Lake, speak to the need for further field studies.

Structures and kinematics of the Utik Lake greenstone belt

The Utik Lake Shear Zone, as delineated by Milligan and Take (1954) and Weber (1974), is best exposed along the south shore of Mistuhe Island and is traceable to the east-northeast all the way into the narrows of southeastern Utik Lake (Figure GS-10-2). Previous mapping interpreted the Utik Lake Shear Zone to represent the southern boundary of the greenstone belt, as it is adjacent to a suite of younger felsic intrusive rocks along the south shore of the lake. In contrast, this new mapping revealed similar metasedimentary rocks along both sides of the southernmost lake channel, which may imply that the southern margin of the Utik Lake greenstone belt is south of the Utik Lake Shear Zone, as defined by previous mapping (Figure GS-10-2). Alternatively, the Utik Lake Shear Zone forms the northern edge of a much wider shear zone extending across the southern channel to the south shore of the lake. The northern boundary of the greenstone belt, in comparison, is much more tightly constrained and located in the channel south of the north shore of central and northwestern Utik Lake. Except for rare mafic dikes, the latter is composed entirely of granodiorite, granite and pegmatite that are void of supracrustal inclusions (Figure GS-10-2).

Within the greenstone belt, most outcrops of supracrustal rocks display at least two planar fabrics. The main, commonly layering-parallel foliation generally strikes east and dips steeply. Dip direction gradually changes from steeply south along the northern margin of the belt, to subvertical in the central part of the belt, to steeply north in the southern parts of the belt. As a result, the greenstone belt forms a keel-shaped structural wedge within the bounding felsic plutonic rocks. A second

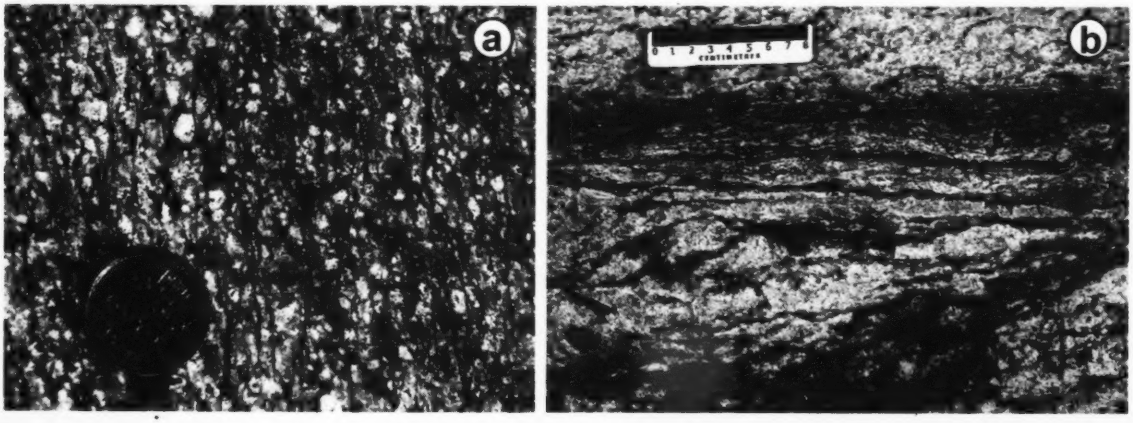

Figure GS-10-10: *Outcrop photographs of highly strained, leucocratic, K-feldspar–rich granite (alaskite) along the Utik Lake Shear Zone, southern Utik Lake:* ***a)*** *ductile recrystallized quartz and brittle-ductile K-feldspar in protomylonitic alaskite (UTM Zone 15, 318730E, 6127451N [NAD83]);* ***b)*** *strongly foliated and dextrally sheared K-feldspar–rich pegmatitic leucogranite or alaskite (UTM Zone 15, 317713E, 6127391N).*

major fabric (S_{n+1}) is a commonly northeast-striking (060–070°) foliation that overprints the main, layering-parallel foliation (S_n). The overprinting foliation (S_{n+1}) is locally developed as dextral shear surfaces, with the two planar fabrics then mimicking the large-scale dextrally sheared lens shape of the greenstone belt at Utik Lake. The S_{n+1} foliation is also axial planar to small-scale (metre to outcrop), open to tight, consistently Z-asymmetric folds that are locally developed on Utik Lake, indicative of an overall dextral sense of shear associated with this deformation event. The east-trending main fabric (S_n) of the belt was reactivated during late-orogenic movement (late- to post-S_{n+1}) and strongly transposed the supracrustal and felsic intrusive rocks along and near the belt margins, resulting in highly strained, locally protomylonitic gneiss (Figure GS-10-10a).

In addition to intersection lineations of the two main planar fabrics, linear structures such as mineral extension lineations are rarely well developed. Where observed, mineral lineations plunge moderately to steeply south-southwest, except for along the northeastern and southwestern margins of the belt, where lineations tend to plunge northeast. In the rare outcrops that display fold structures, fold axes are subparallel to stretching lineations. At map scale, open traceable marker units such as conglomerate and iron formation seem to be openly folded. Folds tend to be Z-asymmetric with sheared limbs subparallel to S_{n+1} shear fabric planes.

A strongly developed early fabric (S_n) in the supracrustal rocks is postdated by the younger suite of diabase and gabbro. These mafic intrusive rocks are variably foliated to massive, and their relationship with the granitoid rocks is uncertain except where alaskite pegmatite is clearly intrusive. On southern Utik Lake, medium- to coarse-grained alaskite bodies are variably foliated and sheared, and underwent cataclasis or mylonitization along high-strain zones (post-S_{n+1}; Figure GS-10-10a), whereas presumably older felsic intrusive gneiss may preserve earlier (S_{n+1}, S_n) fabrics.

Economic considerations

The main economic mineral potential in the Utik Lake area is for orogenic gold and volcanic-associated massive sulphide (VMS) deposits, with minor potential for epithermal and paleoplacer gold mineralization. Volcanic-associated massive sulphide deposits commonly occur within volcanic arcs, particularly those that have undergone extension (Cathles et al., 1983; Syme and Bailes, 1993; Syme et al., 1999). Orogenic gold deposits, in comparison, are known to be localized near or within major transpressive shear zone structures, such as along regional strike at Knee Lake and Monument Bay. At Utik Lake, the potential for volcanic-associated vein and shear-zone gold (e.g., Thorpe and Franklin, 1984) is likely to be highest along the east-trending high-strain zones (and locally developed, subparallel alteration zones) along the northern and southern margins of the greenstone belt. Subsidiary fault structures branching from regional shear zones are common sites of gold mineralization (Eisenlohr et al., 1989).

The principal dextral shear lens geometry of the Utik Lake greenstone belt, caused by the major northeast-trending dextral shears that overprint the generally east-trending fabrics, resulted in dilational structures with net northeast-southwest extension. Areas particularly favourable for focusing gold-bearing metamorphic fluids would thus occur along the transposed belt margins and contacts between major lithological assemblages within the belt (i.e., between metavolcanic flow panels and metasedimentary assemblages). Shear-hosted sulphide occurrences, consisting of disseminated and stringer pyrite±pyrrhotite±chalcopyrite were noted, and samples collected for assay in a high-strain zone along the northeastern and southwestern margins of the greenstone belt. In a similar zone farther to the west, discontinuous sulphide mineralization was traced along strike in a variably but generally strongly altered high-strain zone separating the northern and southern panels of the Utik Lake belt.

Previous prospecting and mineral exploration in the Utik Lake greenstone belt discovered Au, Cu and Zn mineralization of significance (*see* assessment files listed in 'Previous work' section), whereas scientific studies focused on the unique occurrences of alteration pipes in basalt, associated banded iron formation and auriferous chert (Weber, 1974; Bernier and MacLean, 1989). Silicate±oxide–facies banded iron formation is known to form potential traps for sulphide and precious metal (Au) fluids along veins and fractures, where the iron formation was reduced (e.g., Phillips et al., 1984). Several occurrences of sulphidized, silicate-oxide banded iron formation were observed at Utik Lake (located on Böhm and Kremer, 2007). The alteration pipes (black smokers) in pillow basalt in the southernmost mafic metavolcanic panel at Utik Lake are associated with discordant silicification and iron-magnesium alteration. Exhalite deposits from these pipes formed banded iron formation and auriferous, sulphide-bearing chert up to several metres thick on top of the basalt flows (Bernier and MacLean, 1989). In addition, disseminated and structurally controlled sulphide is concentrated within and along the pipes and the overlying banded iron formation, chert and argillite. Associated magnetite-sulphide iron formation resulted from volcanic hydrothermal processes, and thus indicates an environment favourable for the formation of epithermal gold deposits.

Potential for paleoplacer gold deposits needs to be further investigated in the locally voluminous fluvial-alluvial conglomerate units at Utik Lake. Their volcanic-associated setting and high fluid permeability make these units highly prospective for Witwatersrand-type placer gold enrichment.

Acknowledgments

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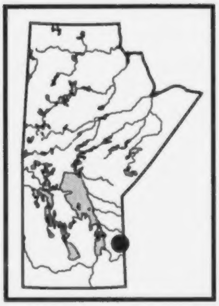
GS-11 Stratigraphic and structural setting of gold mineralization in the Lily Lake area, Rice Lake greenstone belt, Manitoba (NTS 52L11, 14)

by S.D. Anderson



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Summary

Bedrock geological mapping in the Lily Lake area of the Rice Lake greenstone belt has resulted in an improved understanding of the stratigraphy and structure of the Neoarchean Edmunds assemblage, as well as the nature and setting of its contained gold occurrences. In the study area, the Edmunds assemblage consists predominantly of turbiditic siliciclastic rocks that overlie arc-rift volcanic and volcaniclastic rocks of the Gem assemblage along a well-exposed depositional contact. Gold mineralization is hosted by a distinctive association of rock types that include thick-bedded, pebbly quartz greywacke, magnetite iron formation, tonalite-clast–bearing conglomerate, and mafic extrusive and intrusive rocks. These rocks were likely deposited in a very dynamic marginal-marine setting, characterized by voluminous clastic sedimentation, active mafic magmatism and episodic exhalitive activity. Map patterns and younging criteria indicate the presence of tight, upright macroscopic folds, which are extensively overprinted and disrupted by shear fabrics and Z-asymmetric folds that record progressive dextral-transcurrent shear deformation late in the regional orogenic history. The overprinting structures are particularly pervasive and intense within a 500–1000 m thick, east-trending zone that is referred to as the Lily–Banksian deformation corridor. Significant gold occurrences are localized within or along the margins of this corridor, and include three distinct styles of mineralization: shear-hosted quartz-sulphide veins; fault-controlled stockwork-breccia veins and silica-sulphide replacements; and sulphidized iron formation. The tectonic setting, lithostratigraphy and style of these gold occurrences are analogous to economically important lode-gold districts in the Archean Superior and Hearne cratons.

Introduction

The Lily Lake area is located approximately 155 km northeast of Winnipeg in the southeastern portion of the Archean Rice Lake greenstone belt, near the interface between the mainly metavolcanic Uchi Subprovince and the mainly metasedimentary English River Subprovince of the western Superior Province (Figure GS-11-1). During the 2007 field season, three weeks of bedrock geological mapping (1:20 000 scale) were completed in the Lily Lake area in order to refine and expand upon the geological mapping completed in 2006 (Anderson, 2006a, b), which was mainly focused at Gem Lake. The objectives of this study are to document the stratigraphy and structure of the Lily Lake area and gain insight into the nature and setting of its contained gold occurrences. Impetus for this work was provided by the recent discovery of the Roberto gold deposit on the Éléonore property in the James Bay district of Quebec, which is hosted by metasedimentary rocks of the Opinaca Subprovince, near the interface with the mainly metavolcanic La Grande Subprovince, in a setting that is analogous to the English River–Uchi interface in Manitoba. Although traditionally considered less prospective than the adjacent metavolcanic rocks, the discovery of this metasediment-hosted deposit, which is reported to contain an indicated and inferred gold resource of 2.76 million ounces (Simoneau et al., 2007), evidences significant exploration potential.

Regional geology

The Lily Lake area is located in the southeastern portion of the Archean Rice Lake greenstone belt, near the southern margin of the volcano-plutonic Uchi Subprovince of the western Superior Province. In Manitoba, the Rice Lake belt is flanked to the north by the ca. 3.0 Ga continental North Caribou Terrane and to the south by ca. 2.69 Ga metasedimentary rocks and granitoid plutons of the English River Subprovince (Figure GS-11-1). The southern boundary of the North Caribou Terrane is defined by the Wanipigow Fault, which is an east-southeast-trending, subvertical, crustal-scale structure that can be traced along strike for more than 170 km to Red Lake, Ontario. The Uchi–English River boundary is defined by the Manigotagan Fault, which is a similarly oriented structure that can be traced for more than 400 km along strike and is continuous with the Sydney Lake–Lake St. Joseph Fault in Ontario.

Supracrustal rocks in the southeastern portion of the Rice Lake belt constitute several distinct lithotectonic assemblages (*see* Figure GS-11-1; e.g., Poulsen et al., 1996; Bailes et al., 2003), which are interpreted to record continental- and oceanic-arc magmatism, and synorogenic sedimentation within an interpreted north-verging subduction-accretion complex that developed over a 300 Ma time period along the southern margin of the North Caribou Terrane (e.g., Stott and Corfu, 1991; Percival et al., 2002, 2006).

The Garner assemblage consists of a north-younging succession of ca. 2.87–2.9 Ga continental-arc

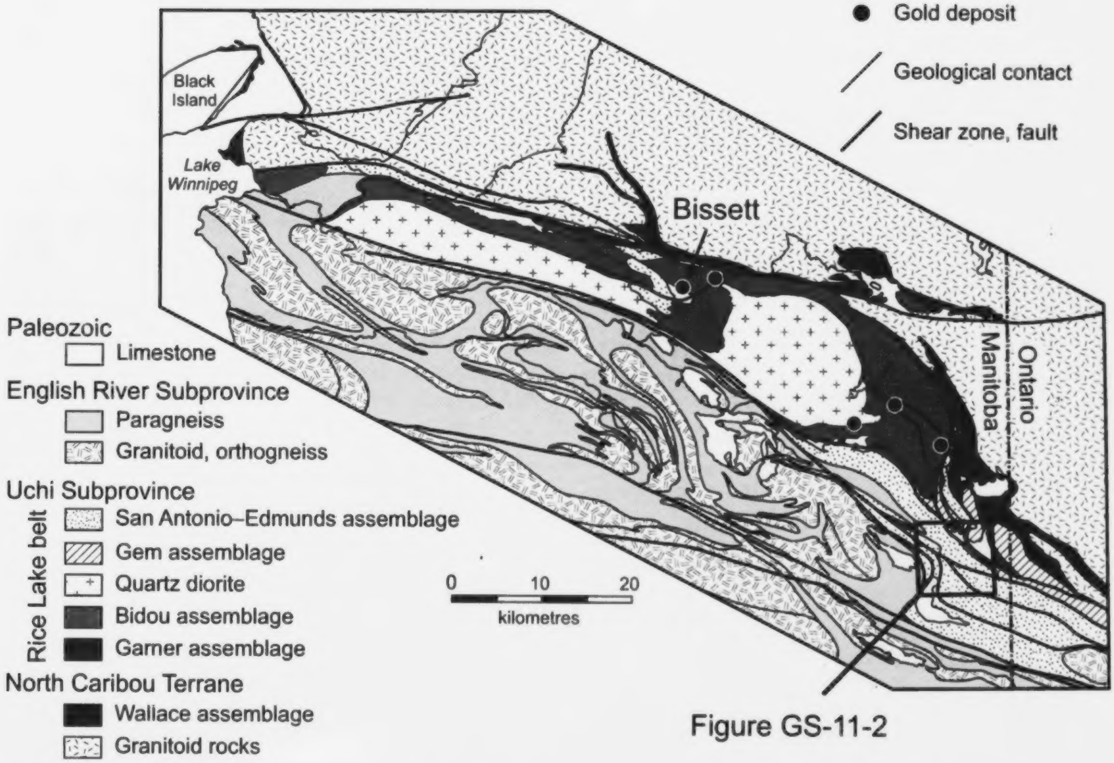
Gold deposit
Geological contact
Shear zone, fault
Black Island
Lake Winnipeg
Bissett
Manitoba
Ontario
Paleozoic
Limestone
English River Subprovince
Paragneiss
Granitoid, orthogneiss
Uchi Subprovince
Rice Lake belt
San Antonio–Edmunds assemblage
Gem assemblage
Quartz diorite
Bidou assemblage
Garner assemblage
North Caribou Terrane
Wallace assemblage
Granitoid rocks
0
10
20
kilometres
Figure GS-11-2

***Figure GS-11-1:** Simplified regional geology of the Rice Lake greenstone belt, showing the principal lithotectonic assemblages and the location of Figure GS-11-2.*

volcaniclastic rocks and plume-related magmatic rocks (Hollings et al., 1999; Anderson, 2006a) that defines the northeastern margin of the Rice Lake belt, and is juxtaposed to the west across the Beresford Lake Shear Zone with the Neoarchean Bidou, Gem and Edmunds assemblages. The Bidou assemblage defines a macroscopic anticlinai culmination in the core of the Rice Lake belt (the Beresford anticline) and is intruded by several synvolcanic tonalite and granodiorite plutons, of which the ca. 2.73 Ga (Turek et al., 1989) Ross River pluton is the most prominent example. The lower portion of the assemblage consists mainly of mid-ocean-ridge (MORB)–like tholeiitic basalt flows, whereas the upper portion consists of a 2.5 km thick succession of ca. 2.73 Ga (Turek et al., 1989) volcaniclastic dacite, which is interpreted to represent an upward transition from back-arc to oceanic-arc magmatism (e.g., Poulsen et al., 1996; Bailes et al., 2003).

As described by Anderson (2005), the Gem assemblage is interpreted to record the initiation of an arc-rift basin within the Bidou oceanic arc (i.e., a possible fore-arc rift; Poulsen et al., 1996). The lower portion of the assemblage consists of a ca. 2.72 Ga (Davis, 1994), subaerial to shallow subaqueous, rhyolitic vent complex composed of high-silica rhyolite flows, coarse flow-lobe breccia units and hypabyssal intrusions (cryptodomes), with minor pumiceous pyroclastic rocks and derived epiclastic rocks. The rhyolite flows and pyroclastic rocks classify as FII- and FIIIa-type rhyolite in the scheme of Lesher et al. (1986), with high-field-strength-element signatures indicative of extension-related, within-plate volcanism (Anderson, 2005). The vent complex is overlain by a thick, possibly rift-fill succession of heterolithic volcaniclastic rocks that includes minor flow-banded to massive dacite and rhyolite flows, gabbro sills, pillowed basalt and basaltic andesite flows, and well-stratified epiclastic rocks.

The Edmunds assemblage concordantly overlies the Bidou and Gem assemblages, and is composed of a thick succession of basinal siliciclastic rocks that consist mainly of monotonous greywacke-mudstone turbidite, with subordinate units of coarse quartz greywacke, polymictic conglomerate and discontinuous layers of chert and iron formation. South of Gem Lake, pillowed basalt flows and dacitic volcaniclastic rocks that were previously considered part of the Gem assemblage (Weber, 1971) are interstratified with the Edmunds assemblage at a variety of scales (e.g., Weber, 1987), indicating that basin infilling was accompanied by mafic and possibly felsic magmatism. Uranium-lead dating of detrital zircons and crosscutting plutons (e.g., Corfu et al., 1995; Davis, 1996) constrain deposition to ca. 2.71–2.70 Ga, coeval with accretion-related orogenesis along the margin of the North Caribou Terrane. These rocks likely represent distal equivalents to the fluvial-alluvial clastic rocks of the ca. 2.70 Ga San Antonio assemblage, which unconformably overlie the Bidou assemblage and occur in discrete, possibly fault-bounded basins adjacent to the Wanipigow Fault.

The English River Subprovince flanks the Uchi Subprovince to the south and consists of ca. 2.69 Ga paragneiss, orthogneiss and granitoid plutons that formed during high-T–low-P regional metamorphism of a thick succession of ca. 2.7 Ga marine turbiditic sedimentary rocks (Corfu et al., 1995) that are the distal equivalents to the Edmunds assemblage. Along the south margin of the Rice Lake belt, high-grade paragneiss is tectonically juxtaposed with lower grade rocks of the Rice Lake belt along greenschist-facies (i.e., retrograde) high-strain zones (e.g., McRitchie and Weber, 1971), which include the Manigotagan Fault and subsidiary structures.

Local geology

The geology of the Lily Lake area has been investigated by Wright (1932), Stockwell (1938), Russell (1952), Weber (1971, 1987) and Anderson (2006a, b). As described by Anderson (2006a), the Lily Lake area is underlain mainly by marine sedimentary rocks of the Edmunds assemblage, which lie in depositional contact to the north with the underlying arc-rift volcanic and volcaniclastic rocks of the Gem assemblage (Figure GS-11-2). In the study area, the top of the Gem assemblage is

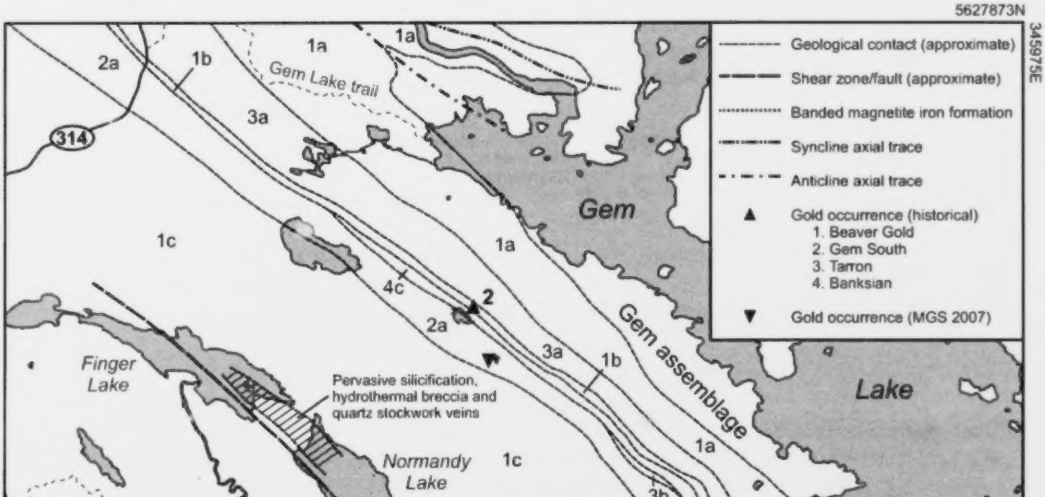
5627873N
345975E
337959E
5622711N
Geological contact (approximate)
Shear zone/fault (approximate)
Banded magnetite iron formation
Syncline axial trace
Anticline axial trace
Gold occurrence (historical)
1. Beaver Gold
2. Gem South
3. Tarron
4. Banksian
Gold occurrence (MGS 2007)
Gem Lake
Gem assemblage
Gem Lake trail
314
Finger Lake
Normandy Lake
Lily Lake
Nora Lake
Banksian Lake
Slate Lake
Manigotagan River
Diana mine trail
Pervasive silicification, hydrothermal breccia and quartz stockwork veins
Figure GS-11-3
0
1
kilometre
1a
1b
1c
2a
2b
3a
3b
3c
4a,c
4b
4c
Edmunds assemblage
4. Mafic volcanic and intrusive rocks
4a) pillowed and massive basalt flows; minor interflow volcaniclastic rocks
4b) gabbro
4c) tectonite of uncertain precursor
3. Conglomerate
3a) polymictic; mainly local detritus
3b) polymictic; abundant exotic detritus
3c) monolithic; dacite detritus
2. Quartz greywacke; pebbly and thick-bedded
2a) homogeneous; minor mudstone interbeds
2b) heterogeneous (see text); includes banded magnetite iron formation
1. Greywacke-mudstone tubidite; thin-bedded
1a) minor chert and felsic volcanic sandstone
1b) interlayered with magnetite iron formation
1c) monotonous

Figure GS-11-2: *Simplified geology of the Edmunds assemblage in the Lily Lake area, southeastern Rice Lake greenstone belt, showing the location of Figure GS-11-3 and the gold occurrences described in the text. For simplicity, the internal geology of the Gem assemblage, which lies in depositional contact with the Edmunds assemblage along the southwest shoreline of Gem Lake, is not shown.*

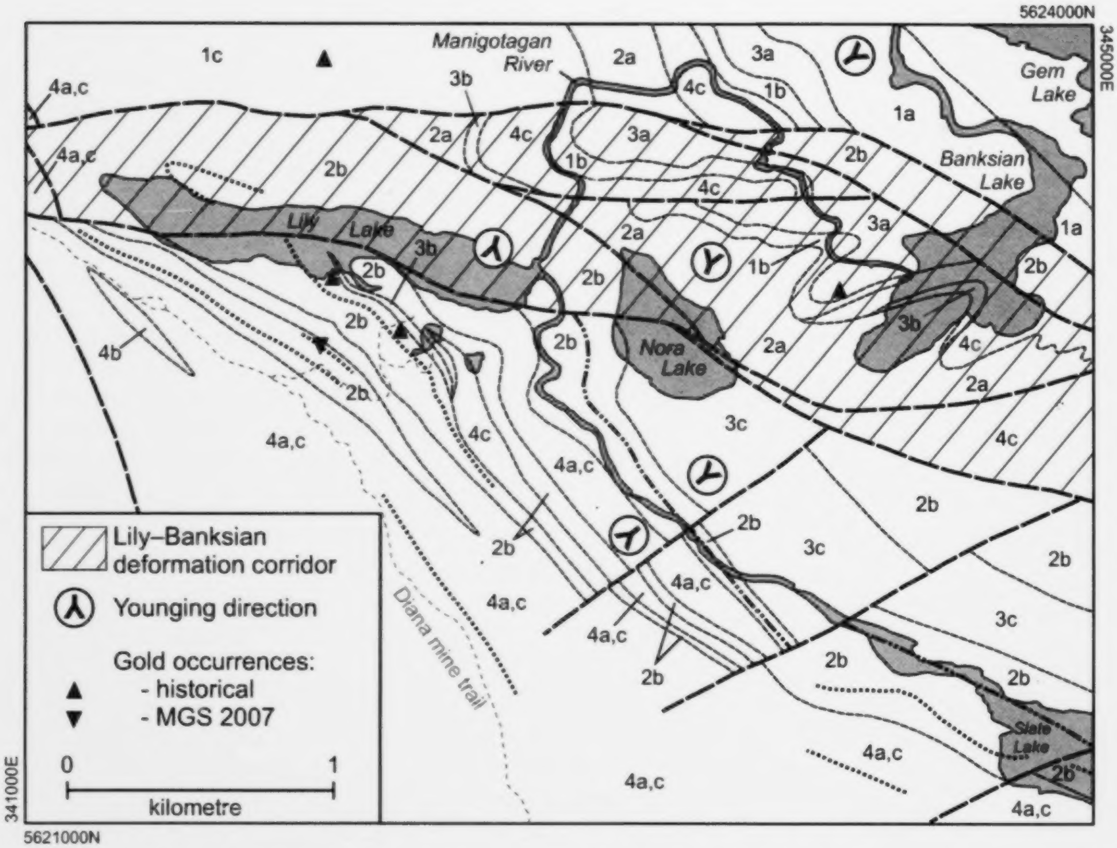

Figure GS-11-3: Detailed geology of the Edmunds assemblage in the Lily–Banksian lakes area. See Figure GS-11-2 for explanation of unit codes and map symbols.

defined by an approximately 200 m thick package of felsic volcaniclastic rocks, with minor intercalated pillowed basaltic andesite flows and derived epiclastic rocks. These rocks are well exposed along the top of the high outcrop ridge that extends along the southwest shoreline of Gem Lake, and lie in sharp depositional contact to the southwest with the Edmunds assemblage. Massive dacitic crystal tuff, which weathers light grey-green to buff, is the predominant rock type and contains minor intercalations of monolithic breccia, tuff-breccia and lapilli tuff. The basaltic andesite flows are dark green to light grey-green, fine to medium grained, and aphyric to sparsely plagioclase phyric. Massive and pillowed flows range up to 40 m thick and characteristically contain 1–5% round to slightly elongate quartz amygdules that range up to 7.0 cm in size, suggesting a shallow-water eruptive setting.

South of Gem Lake, map patterns and younging criteria in the Edmunds assemblage indicate the presence of tight, upright macroscopic folds, which are extensively overprinted and disrupted by shear fabrics and Z-asymmetric folds that record progressive dextral transcurrent shear deformation associated with regional late-orogenic shortening. The overprinting structures are particularly pervasive and intense within a 500–1000 m thick zone that trends in an easterly direction through Lily Lake and Banksian Lake, and is thus referred to as the Lily–Banksian deformation corridor (Figure GS-11-3). North of the deformation corridor, the Edmunds assemblage consists of a generally southwest-younging succession on the south limb of the regional-scale Beresford anticline. South of the deformation corridor, younging criteria in the Edmunds assemblage define the axial trace of a macroscopic isoclinal syncline that trends along the Manigotagan River from Lily Lake to Slate Lake and is thus referred to as the Slate Lake syncline. Metamorphic mineral assemblages throughout the study area indicate low to middle greenschist-facies regional metamorphism.

Lithostratigraphy north of the Lily–Banksian deformation corridor

North and east of Lily Lake, on the south limb of the Beresford anticline, the Edmunds assemblage consists of a distinctive and internally consistent stratigraphic succession that has been mapped continuously along with accretion-related orogenesis along the margin of the North Caribou Terrane. These rocks likely represent distal equivalents to the fluvial-alluvial clastic rocks of the ca. 2.70 Ga San Antonio assemblage, which unconformably overlie the Bidou assemblage and occur in discrete, possibly fault-bounded basins adjacent to the Wanipigow Fault.

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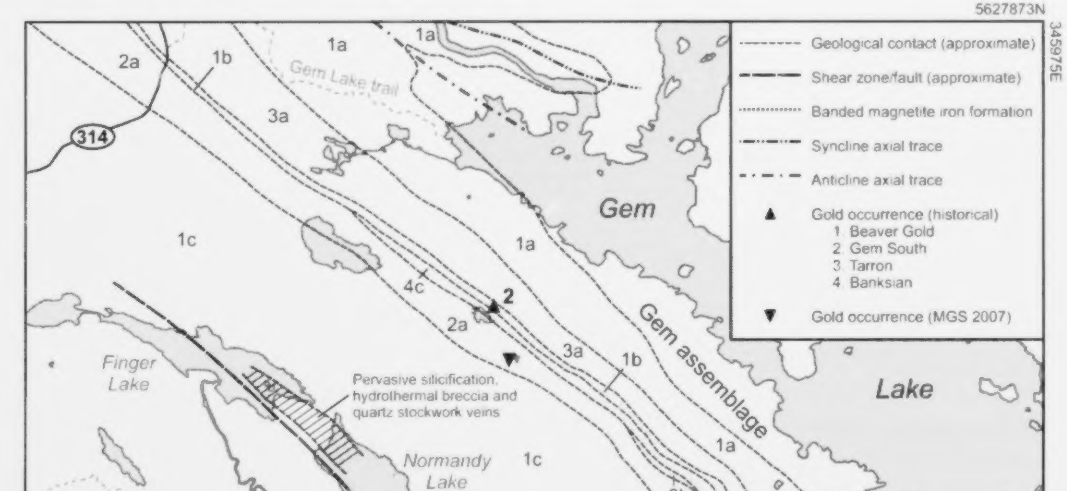
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Edmunds assemblage
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Gem Lake
Gem assemblage
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Normandy Lake
Lily Lake
Nora Lake
Banksian Lake
Slate Lake
Manigotagan River
Diana mine trail
314
Pervasive silicification, hydrothermal breccia and quartz stockwork veins
Figure GS-11-3
0
1
kilometre

Figure GS-11-2: Simplified geology of the Edmunds assemblage in the Lily Lake area, southeastern Rice Lake greenstone belt, showing the location of Figure GS-11-3 and the gold occurrences described in the text. For simplicity, the internal geology of the Gem assemblage, which lies in depositional contact with the Edmunds assemblage along the southwest shoreline of Gem Lake, is not shown.

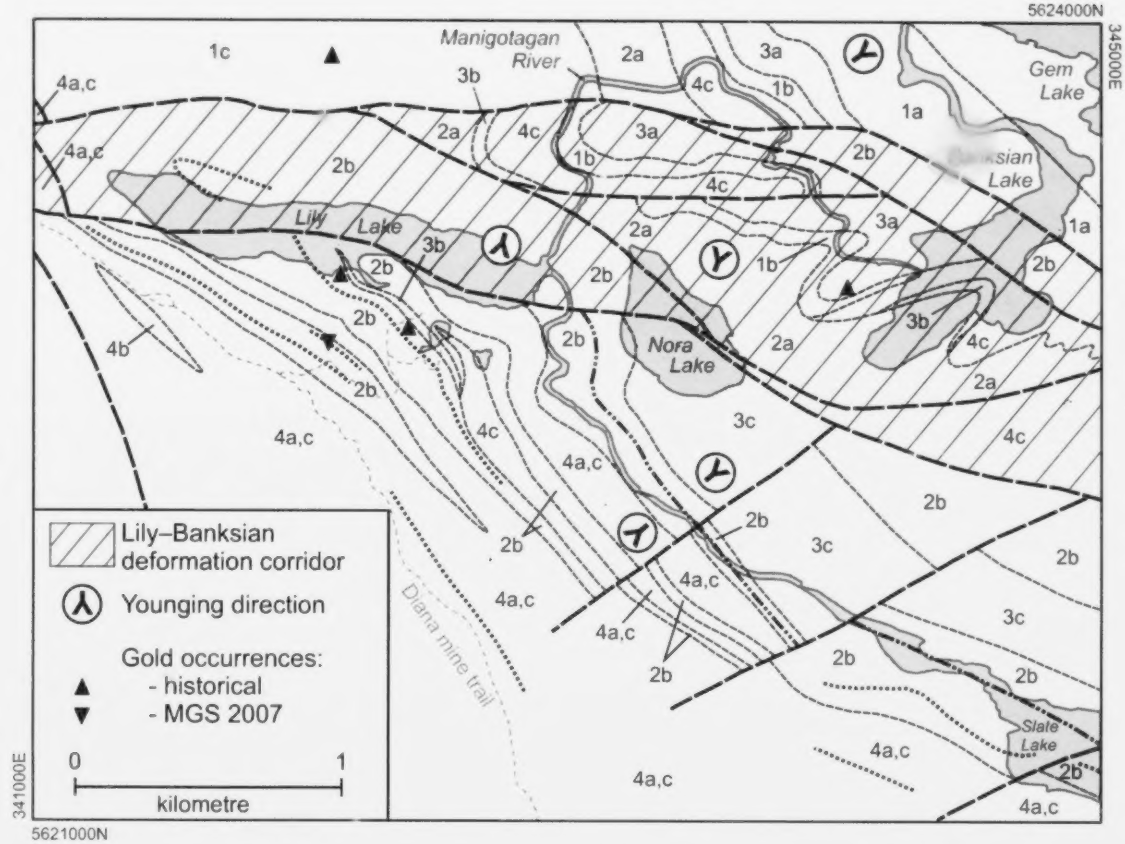

Figure GS-11-3: Detailed geology of the Edmunds assemblage in the Lily–Banksian lakes area. See Figure GS-11-2 for explanation of unit codes and map symbols.

defined by an approximately 200 m thick package of felsic volcaniclastic rocks, with minor intercalated pillowed basaltic andesite flows and derived epiclastic rocks. These rocks are well exposed along the top of the high outcrop ridge that extends along the southwest shoreline of Gem Lake, and lie in sharp depositional contact to the southwest with the Edmunds assemblage. Massive dacitic crystal tuff, which weathers light grey-green to buff, is the predominant rock type and contains minor intercalations of monolithic breccia, tuff-breccia and lapilli tuff. The basaltic andesite flows are dark green to light grey-green, fine to medium grained, and aphyric to sparsely plagioclase phyric. Massive and pillowed flows range up to 40 m thick and characteristically contain 1–5% round to slightly elongate quartz amygdules that range up to 7.0 cm in size, suggesting a shallow-water eruptive setting.

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Lithostratigraphy north of the Lily–Banksian deformation corridor

North and east of Lily Lake, on the south limb of the Beresford anticline, the Edmunds assemblage consists of a distinctive and internally consistent stratigraphic succession that has been mapped continuously along strike for approximately 9.5 km. This succession ranges up to 2.2 km thick and consists, from base to top, of 1) thin-bedded greywacke-mudstone turbidite; 2) locally derived, polymictic pebble conglomerate; 3) thin-bedded greywacke-mudstone turbidite and magnetite iron formation; 4) mafic tectonite of uncertain precursor; 5) tonalite-clast–bearing conglomerate; 6) thick-bedded pebbly greywacke turbidite; and 7) thin-bedded greywacke-mudstone turbidite (Figure GS-11-4). With the exception of the mafic tectonite, this association of rock types corresponds closely to the classical facies association proposed by Walker (1978) for a submarine-fan depositional setting.

The base of the Edmunds assemblage consists of a 200–400 m thick turbidite succession composed of interbedded greywacke and graphitic mudstone (unit 1a). The basal contact with the Gem assemblage is well exposed in several locations and is defined by a unit of thin-bedded to laminated cherty mudstone of variable thickness, suggesting that basin infilling was preceded by a relatively sediment-starved, quiescent interval. Individual greywacke beds are typically fine grained, 2–10 cm thick and normally graded, with sharp basal contacts. Rare examples of complete ('ABCDE') Bouma sequences (Figure GS-11-5a) indicate deposition from turbidity currents, likely in a mid-fan setting. Included in this succession are rare interlayers of pebble conglomerate, white-grey felsic volcanic sandstone and laminated black chert, which are typically 0.5–1.5 m thick and point to episodic variations in sediment influx.

The turbidite succession is overlain by a 150–400 m thick unit of polymictic, pebble to cobble conglomerate (unit 3a). The conglomerate is generally massive, poorly sorted and matrix supported, suggesting deposition from slump-related, submarine debris flows. Well-rounded to subangular clasts are typically 2–15 cm across and consist mainly of grey, aphyric to sparsely feldspar-phyric, felsic volcanic material, which was likely derived from the underlying Gem assemblage; exotic clasts (e.g., quartzite, tonalite, vein quartz) are absent. The matrix consists of fine- to medium-grained feldspathic greywacke that lacks coarse detrital quartz.

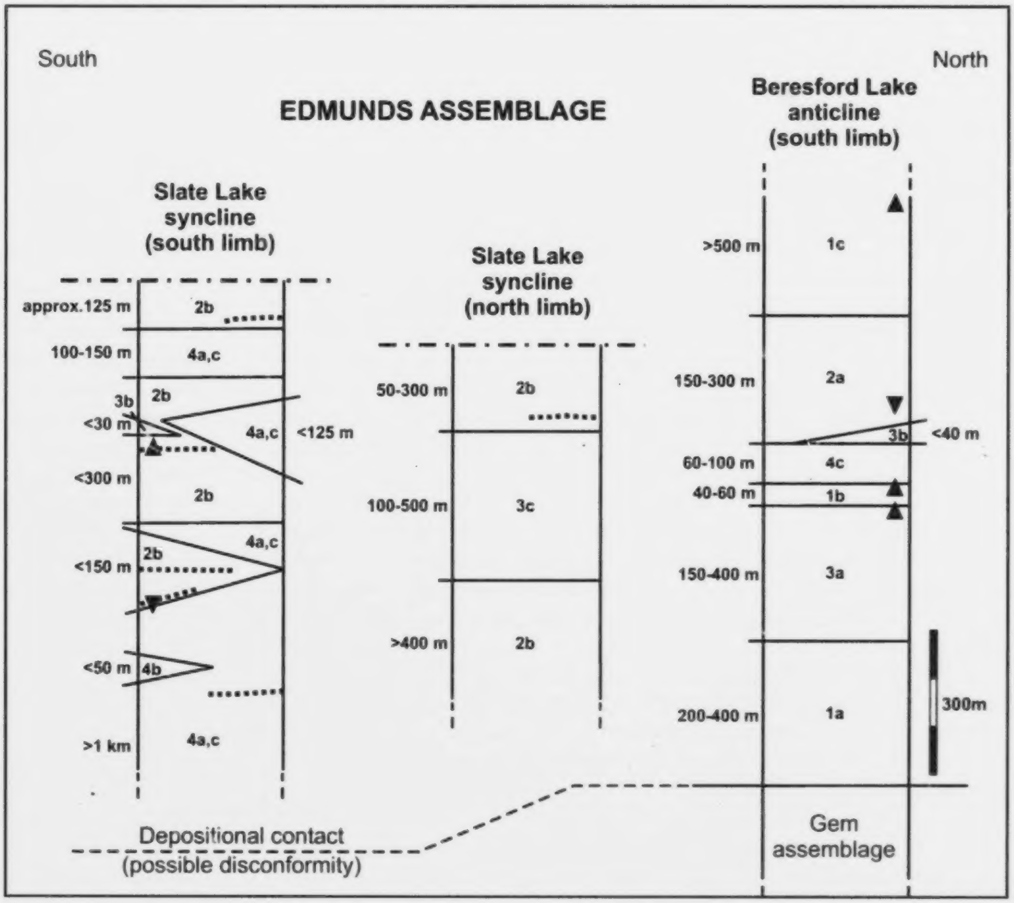
South
North
EDMUNDS ASSEMBLAGE
Slate Lake syncline (south limb)
approx.125 m
2b
100-150 m
4a,c
3b
2b
<30 m
4a,c
<125 m
<300 m
2b
4a,c
2b
<150 m
<50 m
4b
>1 km
4a,c
Slate Lake syncline (north limb)
50-300 m
2b
100-500 m
3c
>400 m
2b
Beresford Lake anticline (south limb)
>500 m
1c
150-300 m
2a
3b
<40 m
60-100 m
4c
40-60 m
1b
150-400 m
3a
200-400 m
1a
300m
Gem assemblage
Depositional contact (possible disconformity)

Figure GS-11-4: *Simplified stratigraphic columns showing the lithostratigraphy of the Edmunds assemblage in the Lily Lake area, southeastern Rice Lake greenstone belt. See Figure GS-11-2 for explanation of unit codes.*

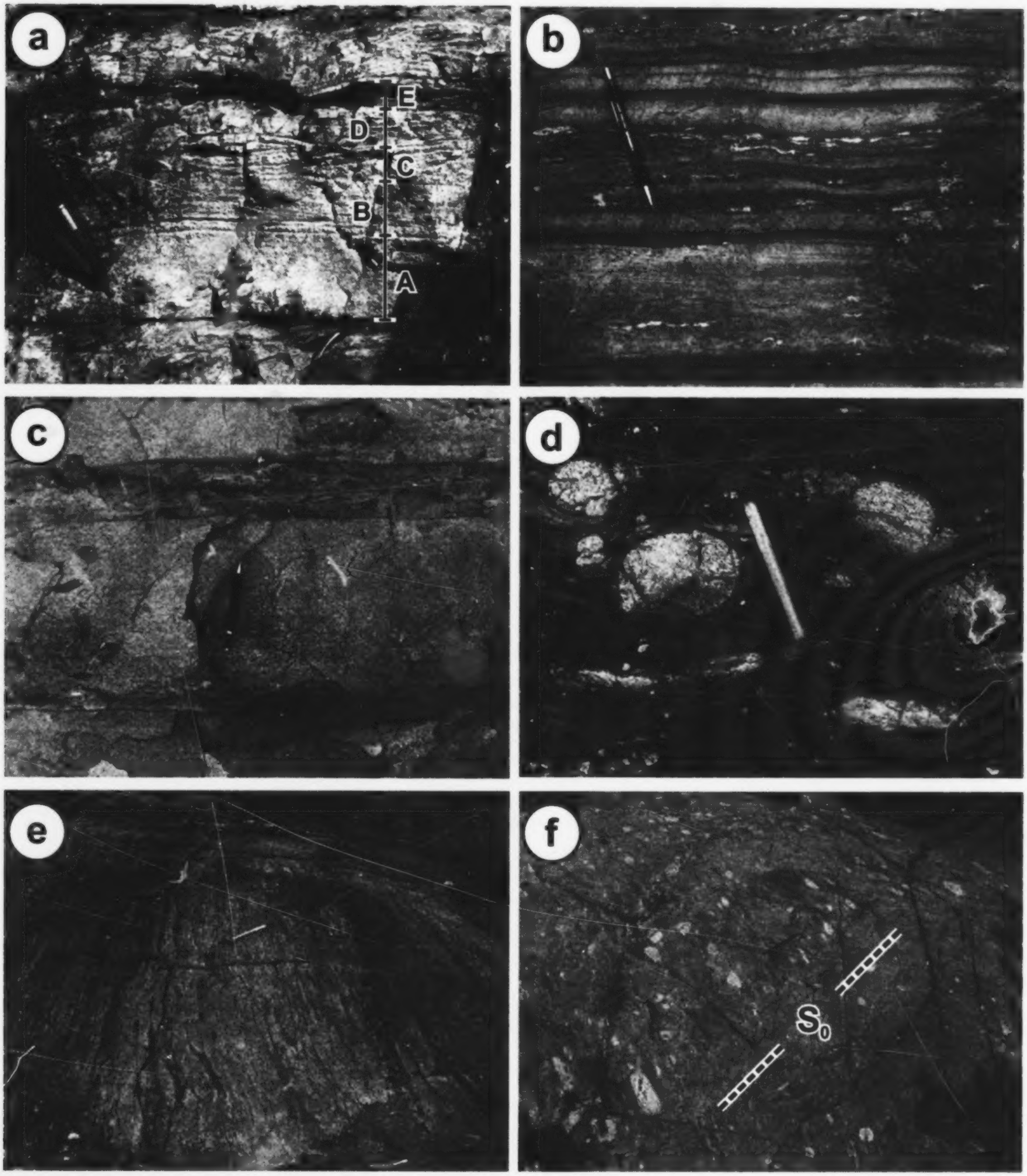

***Figure GS-11-5:** Outcrop photographs of rock types in the Lily Lake area, southeastern Rice Lake greenstone belt: **a)** turbidite exhibiting 'ABCDE' Bouma sequence, southwest of Gem Lake; **b)** greywacke-mudstone turbidite with interlayered magnetite iron formation, southwest of Gem Lake; **c)** pebbly quartz greywacke bed showing normal grading, Lily Lake; **d)** tonalite-boulder conglomerate, north of Lily Lake; **e)** pillow structures preserved in low-strain domain in mafic tectonite, southwest of Lily Lake; **f)** faintly stratified dacite conglomerate, south of Nora Lake.*

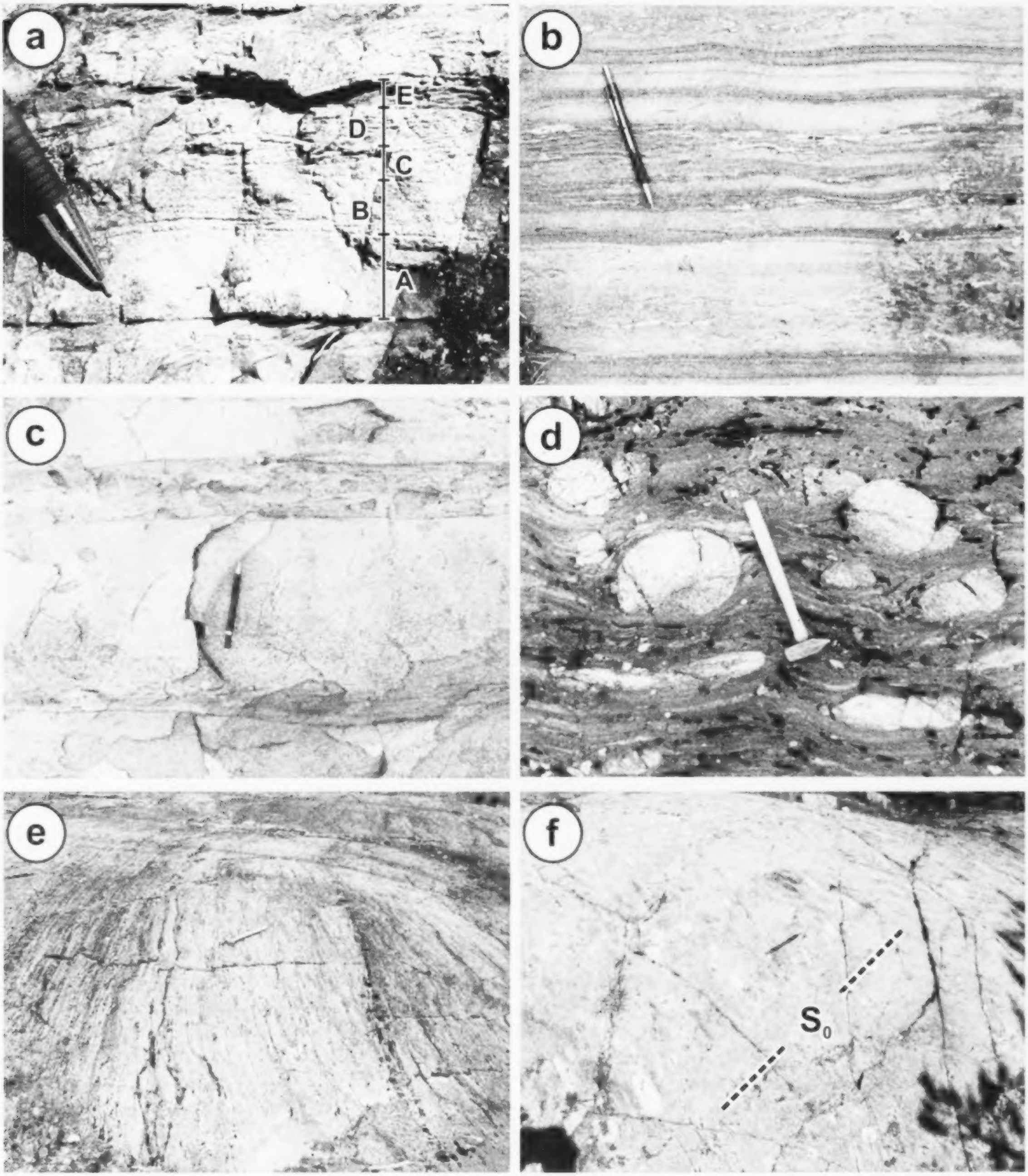

Figure GS-11-5: *Outcrop photographs of rock types in the Lily Lake area, southeastern Rice Lake greenstone belt:* ***a)*** *turbidite exhibiting 'ABCDE' Bouma sequence, southwest of Gem Lake;* ***b)*** *greywacke-mudstone turbidite with interlayered magnetite iron formation, southwest of Gem Lake;* ***c)*** *pebbly quartz greywacke bed showing normal grading, Lily Lake;* ***d)*** *tonalite-boulder conglomerate, north of Lily Lake;* ***e)*** *pillow structures preserved in low-strain domain in mafic tectonite, southwest of Lily Lake;* ***f)*** *faintly stratified dacite conglomerate, south of Nora Lake.*

The conglomerate is overlain by a distinctive, 40–60 m thick interval of thinly bedded greywacke-mudstone turbidite, which is rhythmically interstratified with magnetite iron formation and includes minor beds of laminated cherty mudstone (unit 1b; Figure GS-11-5b). The individual turbidite units are generally 1–5 cm thick and composed of fine- to medium-grained greywacke that grades continuously upwards into laminated mudstone ('AE' turbidite). The mudstone beds are overlain by laminated beds of magnetite iron formation that range up to 10 cm thick. The resulting, 2–15 cm thick, greywacke–mudstone–iron formation 'triplets' are locally organized into fining- and thinning-upward cycles, ranging from 0.2 to 1.0 m thick, within larger fining- and thinning-upward cycles that range from 5 to 10 m thick. These features are indicative of mixed clastic and chemical sedimentation in a sediment-starved lower-fan setting. Similar rocks have been described in a submarine-fan succession along the southern margin of the Beardmore-Geraldton greenstone belt (Barrett and Fralick, 1989), near the interface between the Wabigoon and Quetico subprovinces. As described by Klein (2005), the iron formation units likely result from basinal (below wave base) chemical precipitation, with iron and silica sourced mainly from submarine hydrothermal activity.

In the northwestern portion of the mapped area, the turbidite–iron formation unit is overlain by a succession of thick-bedded quartz greywacke and mudstone that ranges from 150 to 300 m thick and contains minor beds of pebble conglomerate (unit 2a). The greywacke is buff to pale grey, medium to very coarse grained, and typically contains 10–30% detrital quartz. Individual beds range from 0.2 to 2.0 m thick and generally exhibit normal size-grading from coarse- or very coarse grained pebbly greywacke at the base to fine-grained greywacke at the top (Figure GS-11-5c). The beds are planar-tabular, with sharp and scoured basal contacts; crossbedding is absent. The fine-grained greywacke grades upward into brown mudstone interbeds that range up to 15 cm thick and generally account for 5–10% of the outcrops. These features indicate deposition via turbidity currents, likely in a mid-fan setting. Medium- to coarse-grained greywacke also forms massive beds up to 3 m thick, which were likely deposited from higher density grain flows. The pebble conglomerate layers are 20–50 cm thick and include subangular to well-rounded clasts of vein quartz and medium-grained tonalite, indicating a significant change in sediment provenance (*see* below).

In the area northeast of Lily Lake and extending towards Banksian Lake, the base of the thick-bedded quartz greywacke succession is locally marked by a distinctive unit of tonalite-clast–bearing cobble to boulder conglomerate (unit 3b). This unit ranges up to 40 m thick locally and forms lenticular bodies of apparently limited strike length. The conglomerate is poorly sorted and matrix supported, and ranges from massive to faintly stratified. In the westernmost outcrops, well-rounded (in many cases nearly spherical) to subrounded cobbles and boulders of tonalite predominate, and range up to 50 cm across (Figure GS-11-5d). The matrix consists of brown, fine-grained greywacke. These features indicate deposition from slump-related submarine debris flows composed of fluvially transported detritus. Toward the southeast, the proportion of tonalite clasts decreases and the conglomerate contains abundant clasts of porphyritic andesite and dacite, black aphyric rhyolite and vein quartz, with local beds of pebbly quartz greywacke. This conglomerate, together with the overlying quartz greywacke succession, records a major influx of fluvial sediment into the submarine fan, with a change to a more deeply eroded, and likely more distant, source area.

The thick-bedded quartz greywacke succession is overlain by a monotonous succession of greywacke-mudstone turbidite that is at least 500 m thick (unit 1c). This succession is composed of thinly interbedded greywacke and graphitic mudstone, and is thus substantially similar to the rocks at the base of the Edmunds assemblage. This succession is dominated by AE turbidite units, suggesting deposition in a mid- to lower-fan setting.

Throughout much of the map area, the interface between units 1b and 2a is marked by a laterally continuous, 60–100 m thick unit of rusty brown to green mafic tectonite of uncertain precursor (unit 4c). Most outcrops consist of strongly foliated chloritic mylonite and phyllonite. In places, however, this unit includes a dark green to brown, fine- to medium-grained, apparently massive and equigranular rock that exhibits a faint subophitic to ophitic texture defined by 0.5–1.5 mm feldspar crystals in a matrix of chlorite and actinolite. Other outcrops consist of a light green to grey porphyritic rock, which contains subhedral, 2–5 mm plagioclase phenocrysts (10–20%) in a fine-grained feldspathic and chloritic matrix. In one location, this unit varies from dark green-brown and equigranular on the northeast, to light green-grey and porphyritic on the southwest, perhaps as a result of *in situ* differentiation. Most outcrops are moderately to strongly magnetic and contain finely disseminated sulphides, consisting mainly of pyrrhotite and pyrite, with traces of chalcopyrite. In the absence of clear textural indications of alternative origins, these aspects are interpreted to indicate an intrusive origin for this unit. Texturally similar mafic sills are observed in the underlying map units.

Lithostratigraphy south of the Lily–Banksian deformation corridor

The stratigraphy of the Edmunds assemblage is considerably more complex in the area southeast of Lily Lake (Figures GS-11-3, -4). Here, the principal rock types include monolithic dacite conglomerate and variably tectonized mafic volcanic and intrusive rocks, which define lenticular units that are intercalated on scales ranging from metres to several hundreds of metres with internally complex units of mixed clastic and chemical (exhalitive iron formation) sedimentary rocks. The sedimentary units are cut by mafic dikes and sills of similar texture and geochemical signature to intercalated mafic flows. This, in conjunction with evidence of depositional contact relationships observed in the field, indicates that this section is most likely a stratigraphic succession, as opposed to a thrust imbricate. Hence, the apparently abrupt lateral and vertical facies changes that characterize this succession are interpreted to result from primary depositional processes within a very dynamic, marginal-marine depositional environment characterized by active mafic volcanism, episodic exhalitive activity and voluminous clastic sedimentation. This succession is at least 1.5 km thick on the south limb of the Slate Lake syncline, and younging criteria consistently indicate tops to the northeast. On the north limb of the syncline, the succession is approximately 800 m thick and exhibits consistent younging to the southwest.

South limb

On the south limb of the Slate Lake syncline, the base of the section is marked by a thick (>1 km) succession of variably tectonized mafic volcanic flows and intrusive rocks. Mafic tectonite (unit 4c) predominates in the upper (northeastern) portion of the succession, and consists of chlorite-carbonate phyllonite that is anastomosed around relatively low-strain domains in which primary textures are locally preserved (Figure GS-11-5e). Most of this succession appears to consist of pillowed and massive basalt flows (unit 4a). The basalt weathers buff to rusty brown to green and is grey-green on fresh surfaces. Most specimens are fine grained, aphyric and nonamygdaloidal, although sparse feldspar phenocrysts (1–2%; 2–5 mm) and quartz amygdules (1–3%; 1–5 mm) are observed locally. Pillows preserved in low-strain enclaves within the tectonite are wispy to bun shaped and less than 2.0 m in maximum dimension, with chloritic selvages <1.5 cm thick and <5% interpillow material (mainly carbonate). Individual flows range up to at least 10 m thick and are locally capped by 0.5–3.0 m thick layers of flow-top breccia. Massive flows range up to 5 m thick and locally transition upward into pillowed and/or brecciated flow tops. In these locations, it is apparent that strain was strongly partitioned into less-competent breccia layers between the individual flows. The basalt flows are intruded by dikes and sills of fine- to medium-grained, locally plagioclase-porphyritic gabbro; individual gabbro sills range up to at least 50 m thick (unit 4b). Discordant dikes of gabbro up to 3 m thick form a significant component (approx. 5–10%) of some outcrops, and are also observed to cut the overlying clastic sedimentary rocks. The available geochemical data (five samples) indicate two distinct types of lava: calcalkaline basaltic andesite of oceanic-arc affinity and tholeiitic basalt of transitional oceanic-arc–E-MORB affinity (Anderson, unpublished data, 2006).

Towards the northeast, the mafic volcanic rocks are intercalated with clastic and chemical sedimentary rocks, which locally form heterogeneous, well-stratified units up to 300 m thick (unit 2b). Thick-bedded quartz greywacke, which is texturally similar to that described previously (unit 2a), is the predominant rock type and is intercalated with lenticular strata of polymictic conglomerate, thin-bedded greywacke-mudstone turbidite, and graphitic mudstone. This unit also contains minor strata of monolithic dacite conglomerate, banded magnetite-chert iron formation, feldspathic greywacke, mafic volcanic sandstone and laminated black chert. Individual quartz greywacke beds range up to 1.5 m thick and are separated by thin (<10 cm) beds of fine-grained greywacke or mudstone. These beds characteristically exhibit normal size grading and well-developed basal lag deposits composed of angular mudstone rip-up clasts, and more rounded lithic clasts and quartz pebbles. Lenticular layers of polymictic conglomerate range up to 25 m thick and contain unsorted, typically subangular to well-rounded, matrix-supported clasts, which range in size up to 25 cm, in a very coarse grained, quartz-rich matrix. Clast types include porphyritic to aphyric dacite, black aphyric rhyolite, quartz-feldspar porphyry, vein quartz, magnetite iron formation, tonalite and orthoquartzite. The latter two clast types do not appear to be of local provenance, and suggest a probable source area in the ca. 3.0 Ga North Caribou Terrane. This inference is supported by the predominance of ca. 2.92–3.01 Ga detrital zircons in a sample of this material collected in 2006 for detrital zircon U-Pb analysis (Anderson, unpublished data, 2007).

North limb

The lithostratigraphy on the north limb of the Slate Lake syncline is dominated by a remarkably homogeneous unit of monolithic dacite conglomerate (unit 3c) that can be traced along strike for 3.0 km and increases in thickness from 100 m in the southeast to just over 500 m in the northwest. Along the upper and lower contacts, this conglomerate is locally heterolithic and contains minor interbeds of polymictic pebble conglomerate and thin-bedded feldspathic greywacke and graphitic mudstone of unit 2b. Dacite conglomerate layers, which do not exceed 10 m thick, are also present on the south limb of the fold, and thus provide a stratigraphic link across the hinge of the fold. This conglomerate is massive to very faintly stratified, unsorted and matrix supported, and is composed almost exclusively of buff to light green–weathering, plagioclase-phyric dacite clasts, with rare clasts of slightly darker green plagioclase-phyric andesite (Figure GS-11-5f). The dacite clasts range in shape from well rounded to subangular, and in size up to 1.5 m (typically 5–10 cm). No examples of obviously second-cycle (i.e., volcaniclastic) clasts were observed. The matrix consists of medium- to coarse-grained feldspathic wacke that contains 30–40% subhedral feldspar crystals <1.5 mm in size; coarse detrital quartz is absent from the matrix. These features, coupled with the significant stratigraphic thickness, are interpreted to indicate that the dacite conglomerate on the north limb of the syncline was deposited via an uninterrupted series of large-volume, subaqueous debris flows sourced from a rapidly eroding volcanic arc.

Structural geology

As described by Anderson (2004), mesoscopic overprinting relationships indicate at least six generations of ductile deformation structure in the eastern portion of the Rice Lake greenstone belt. In the Lily Lake area, however, evidence of this deformation history is typically obscured by a pervasive and intense structural overprint associated with late-orogenic transcurrent shear deformation. Nevertheless, map patterns, younging criteria and bedding-cleavage relationships indicate the presence of an early macroscopic syncline, which is correlated with the F_3-generation folds described regionally. The northern limb of this syncline is shared with the F_3 Beresford anticline, which is the dominant structural feature in the core of the Rice Lake belt. On a regional scale, the F_3 folds define tight, upright, doubly plunging structures that trend northwest and are overturned to the southwest. These folds are associated with a regionally developed, axial-planar, S_3 flattening fabric and cleavage that dips subvertically and contains a steeply plunging L_3 elongation lineation. The S_3 fabric locally intensifies into a penetrative transposition fabric, which is particularly well developed along the axial trace of the F_3 syncline on the Manigotagan River between Lily Lake and Slate Lake (Figure GS-11-6a).

In the central portion of the belt at Rice Lake (*see* Anderson, 2004), the S_3 fabric is consistently overprinted at a counterclockwise angle by a finely spaced S_4 crenulation cleavage, and both of these fabrics are overprinted at a clockwise angle by a variably developed S_5 shear band or fracture cleavage that exhibits a consistent dextral sense of asymmetry or offset. In the Lily Lake area, both of these fabrics are at least locally well developed (Figure GS-11-6b, -6c), but appear to be associated with the progressive development of the discrete high-strain zones and Z-asymmetric folds formed during dextral transcurrent shear deformation (i.e., the D_4 and D_5 deformation structures recognized at Rice Lake probably result from separate increments of a regionally progressive dextral transcurrent deformation). South of Lily Lake, the macroscopic F_3 folds are extensively overprinted and disrupted by D_4-D_5 high-strain zones and Z-asymmetric folds. The high-strain zones range up to several hundreds of metres thick and consist of chloritic or sericitic mylonite and ultramylonite (Figure GS-11-6d) that contain steeply dipping mylonitic foliations and shallow-plunging quartz-ribbon and slickenline lineations (Figure GS-11-6e). Kinematic indicators, which include porphyroclast systems, S-C fabrics, shear bands and asymmetric boudin trains, consistently indicate dextral strike-slip shear. Mesoscopic and macroscopic Z-asymmetric folds (F_4-F_5) are pervasive in the Lily Lake area, and are particularly intense in the west-trending Lily–Banksian deformation corridor (Figure GS-11-6f). These folds are gentle to tight, with steeply inclined, east-northeast-trending axial planes and steeply plunging hinges. Axial-planar fabrics are only locally developed and, in these locations, consist of a finely spaced crenulation cleavage. Chevron-style Z-folds are common. Rare tight to isoclinal, similar-style Z-folds are also observed, particularly in the mafic tectonite.

Brittle faults are the latest structures observed in the Lily Lake area. These faults strike northwest or northeast and dip subvertically. Offsets are generally right lateral on the northwest-trending faults and mainly left lateral on the northeast-trending faults, which is suggestive of a conjugate relationship. Apparent displacements range up to several hundreds of metres. Where exposed, the faults are characterized by sharp slip surfaces and narrow (<50 cm) zones of cohesive fault breccia and cataclasite, with minor irregular seams of purple or black pseudotachylite. The wallrocks are commonly bleached, with moderate to strong silicification and diffuse arrays of quartz-filled extension fractures.

Exploration history

From 1925 to the present, the Lily Lake area has seen extensive, though intermittent, prospecting activity. Many of the known mineral occurrences in the area were initially staked in 1926 following the discovery of the Diana deposit, which is located 5 km southeast of Lily Lake at Kickley Lake. To date, four significant gold occurrences have been identified in the Lily Lake area (Figure GS-11-2). Prior to 1984, exploration activity was restricted mainly to surficial prospecting for vein-hosted mineralization, and this work lead to the discovery of the Beaver Gold and Banksian occurrences. In 1984, Nelson Baker Geological Services Ltd. completed a reconnaissance rock-chip geochemical survey that covered Gem Lake and extended to the north shore of Lily Lake (Assessment File 93615, Manitoba Science, Technology, Energy and Mines, Winnipeg). This survey identified two areas of significantly anomalous gold and arsenic in bedrock, which are now known as the Gem South and Tarron occurrences.

The Beaver Gold occurrence, discovered by surface prospecting in about 1940, is located on the south shore of Lily Lake. The geology of this occurrence is described by Russell (1952), Theyer and Gaba (1986) and Theyer (1987, 1994). Prior to 1986, the most extensive exploration of the occurrence was reported by Starbird Mines Ltd. in 1959 (A.F. 91322) and Rock Ore Exploration and Development Ltd. in 1976–1977 (A.F. 94291). In 1986, Canhorn Mining Corp. completed an airborne

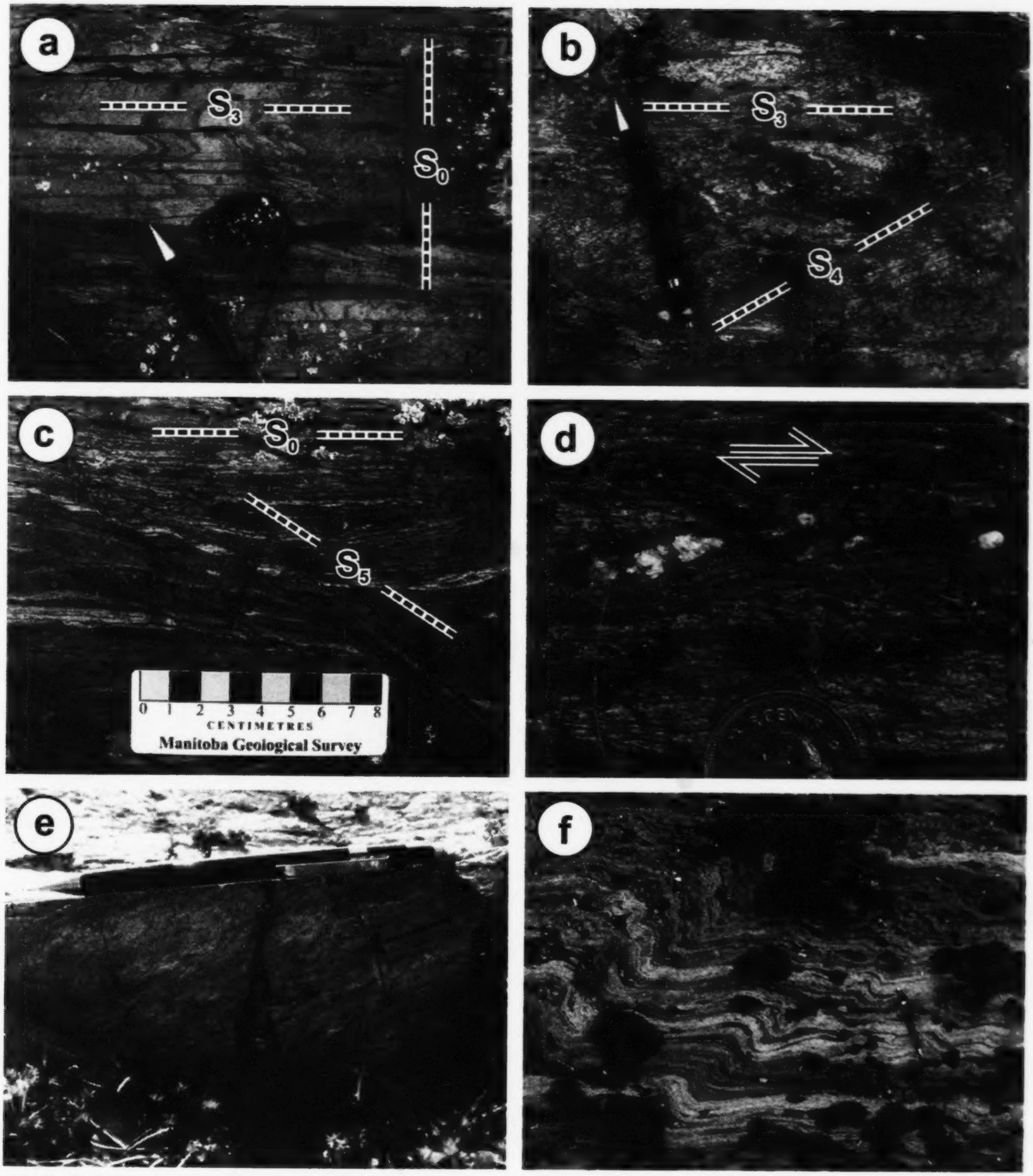

Figure GS-11-6: *Outcrop photographs of deformation structures in the Lily Lake area, southeastern Rice Lake greenstone belt:* ***a)*** *spaced S_3 crenulation cleavage and transposition fabric in the hinge of the Slate Lake syncline, Slate Lake;* ***b)*** *S_3 flattening fabric (defined by elongate clasts) overprinted by finely spaced S_4 crenulation cleavage, north of Slate Lake;* ***c)*** *S_5 shear-band cleavage overprinting S_0-S_3, west of Gem Lake;* ***d)*** *S_4-S_5 mylonitic foliation and asymmetric quartz boudins (dextral) in high-strain zone, Gem Lake;* ***e)*** *shallow-plunging quartz ribbon lineation in S_4-S_5 mylonite, north of Lily Lake;* ***f)*** *Z-asymmetric F_4-F_5 folds in mafic tectonite, Banksian Lake.*

geophysical survey on a large claim group that extended from the south shore of Lily Lake to the west end of Anderson Lake (A.F. 94605, 94606) and included the Beaver Gold occurrence. In 1987, under an option agreement with Canhorn Mining Corp., Mutual Resources Ltd. investigated the Beaver Gold occurrence in detail (A.F. 94588) and identified four zones of gold mineralization hosted by a variably silicified, sulphidized and sericitized unit of greywacke turbidite, bounded by boulder conglomerate and banded-magnetite iron formation (unit 2b). This unit was traced for 850 m along strike and returned up to 12 410 ppb Au over 1.0 m in channel samples. In this interval, visible gold is observed in thin, lenticular veins of smoky grey to black quartz that exhibit narrow wallrock sulphidization haloes containing up to 20% arsenopyrite. In 1988, Mutual Resources Ltd. completed three diamond-drill holes (totalling 304.8 m) to test the occurrence, the best result of which was 5420 ppb Au over 1.47 m in DDH88-3 (A.F. 94589). In 1996, Asquith Resources Inc. acquired the claim group and completed three additional diamond-drill holes (totalling 331.1 m), the best result of which was 9460 ppb Au and 6000 ppm As over 40 cm in LL96-2, within a 14 m thick interval of quartz-veined greywacke with patchy arsenopyrite mineralization (A.F. 94566).

The Gem South occurrence is situated roughly midway between Gem Lake and Normandy Lake, and was identified in 1984 by the reconnaissance rock-chip geochemical survey completed by Nelson Baker Geological Services Ltd., which returned values as high as 630 ppb Au and 10 000 ppm As over the occurrence. In 1984–1985, Amalgamated Mining Development Corp. Ltd. investigated this occurrence through prospecting and rock-chip geochemical sampling, as well as magnetometer, VLF-EM and pulse-EM surveys. This work outlined a northwest-trending zone of stratabound disseminated arsenopyrite mineralization and sparse quartz-arsenopyrite veins associated with interlayered turbidite and magnetite iron formation (unit 1b). This zone was traced for 900 m along strike and surface samples returned values up to 710 ppb Au. Two diamond-drill holes (84-1 and 85-1) were completed to test a 90 m strike length of the anomalous zone. The best results were obtained from DDH84-1, which intersected 13.1 m of arsenopyrite mineralization that contained several narrow intercepts with up to 24 406 ppm As and 2560 ppb Au (A.F. 93616).

The Tarron occurrence is located north of the central portion of Lily Lake, and was discovered in 1985 by exploration crews from OreQuest Consultants Ltd., who were prospecting the area of an anomalous rock-chip sample (2140 ppb Au, 1594 ppm As) collected in 1984 by Nelson Baker Geological Services Ltd. The 1985–1986 work program, undertaken by OreQuest Consultants Ltd. on behalf of Tarron Resources Ltd., involved geological mapping, prospecting, bedrock geochemical sampling and VLF-EM and magnetometer surveys on two claims that extended from Lily Lake to Banksian Lake (A.F. 93110). In the location of the anomalous rock-chip sample, a prospecting crew identified a system of thin (<30 cm) quartz-arsenopyrite veins hosted by sheared and folded greywacke (unit 1c), which returned values up to 42 130 ppb Au in grab samples. Theyer (1987) examined the Tarron occurrence and described fracture-controlled tourmaline mineralization within zones of bleached and silicified wall rock several metres thick. In 1998, Asquith Resources Inc. followed up this work with a program of prospecting, rock geochemical sampling, geological mapping and ground magnetometer surveying north of Lily Lake in the area of the Tarron occurrence (A.F. 94538, 94541), and confirmed the presence of gold values up to 27 100 ppb in quartz veins.

The historical Banksian occurrence, which was described by Russell (1952) and Theyer (1994), is located near the southwest shore of Banksian Lake and consists of several shallow trenches that expose a series of discontinuous blue-black quartz veins hosted by pyrite and arsenopyrite-bearing chlorite schist and iron formation (unit 1b). This occurrence was sampled in 1985 by OreQuest Consultants Ltd. on behalf of Tarron Resources Ltd., and returned values up to 4660 ppb Au in grab samples (A.F. 93110).

Mineralization and alteration

The historical gold occurrences described above, coupled with two new gold occurrences identified by the MGS in 2007, comprise three distinct styles of mineralization: 1) strongly deformed quartz-sulphide veins associated with ductile shear zones; 2) late stockwork-breccia veins and silica-sulphide replacements associated with brittle faults; and 3) sulphidized iron formation.

Shear-hosted quartz-sulphide veins

Gold mineralization at the Tarron, Beaver Gold and Banksian occurrences consists of variably deformed quartz-sulphide veins associated with discrete, generally bedding-parallel, ductile-brittle shear zones. The host rocks typically consist of thick-bedded quartz greywacke (Tarron and Beaver Gold) or iron formation (Banksian). The shear zones dip steeply north or northeast and are characterized by narrow zones of chloritic or sericitic mylonite that contain shallowly plunging slickenline or quartz-ribbon lineations and ubiquitous dextral kinematic indicators. Within these zones, the quartz veins are highly attenuated, boudinaged and folded (Figure GS-11-7a), and rarely exceed 50 cm in thickness, with maximum strike lengths of 25 m. The wallrocks adjacent to the shear zones contain variably transposed Z-folds and local crosscutting arrays of quartz-filled extension fractures. The vein quartz is distinctly grey or black, with a dense 'cherty' texture. Accessory minerals include ankerite, sericite, chlorite, feldspar and calcite. Most veins contain trace to 5% pyrite and arsenopyrite, with the best gold values associated with finely disseminated needles of arsenopyrite. Wallrock alteration haloes are typically narrow (<1 m) and consist of proximal silica-sericite/chlorite-ankerite-sulphide that grades outwards to distal chlorite/sericite-calcite. At the Tarron occurrence, concordant zones of moderate to strong quartz-feldspar alteration are overprinted by brittle, tourmaline-filled fracture arrays. The general characteristics of these auriferous veins are indicative of classical 'mesothermal' or 'orogenic' lode-gold deposits.

Fault-controlled stockwork-breccia veins and silica-sulphide replacements

In 2007, the MGS identified a new gold occurrence southwest of Gem Lake and approximately 450 m southeast of the Gem South occurrence. The occurrence is hosted by thick-bedded quartz greywacke (unit 2a), approximately 100 m stratigraphically above the laterally continuous iron formation (unit 1b) and mafic tectonite (unit 4c). In this area, younging reversals indicate the presence of a macroscopic isoclinal fold closure, which is likely parasitic to the regional-scale Beresford F_3 anticline. The occurrence consists of patchy, irregular zones of moderate to intense silica-sericite-sulphide alteration associated with stratabound arrays of quartz-filled extension fractures, as well as bedding-discordant, northwest-trending faults (Figure GS-11-7b). The zones of most intense alteration, which rarely exceed 1.0 m in thickness, are associated with faults that contain narrow seams of silica-cemented breccia and cataclasite with ghost-like fragments of altered wallrock and 2–5% finely disseminated pyrite and arsenopyrite. Wallrock alteration grades outward from proximal silica-sulphide to distal sericite-silica±sulphide over 0.5–1.0 m. In some cases, the wallrock alteration is sharply bounded by discrete slip surfaces, indicating that fault movement outlasted alteration and vein emplacement. A grab sample of proximal silica-sulphide alteration from one of these faults returned 350 ppb Au and 3270 ppm As.

Similar fault-controlled alteration and veining was described by Anderson (2006a) north of Gem Lake, and was also observed by the author on the neck of land separating Finger Lake and Normandy Lake (*see also* Russell, 1952). In the latter location, intensely silicified

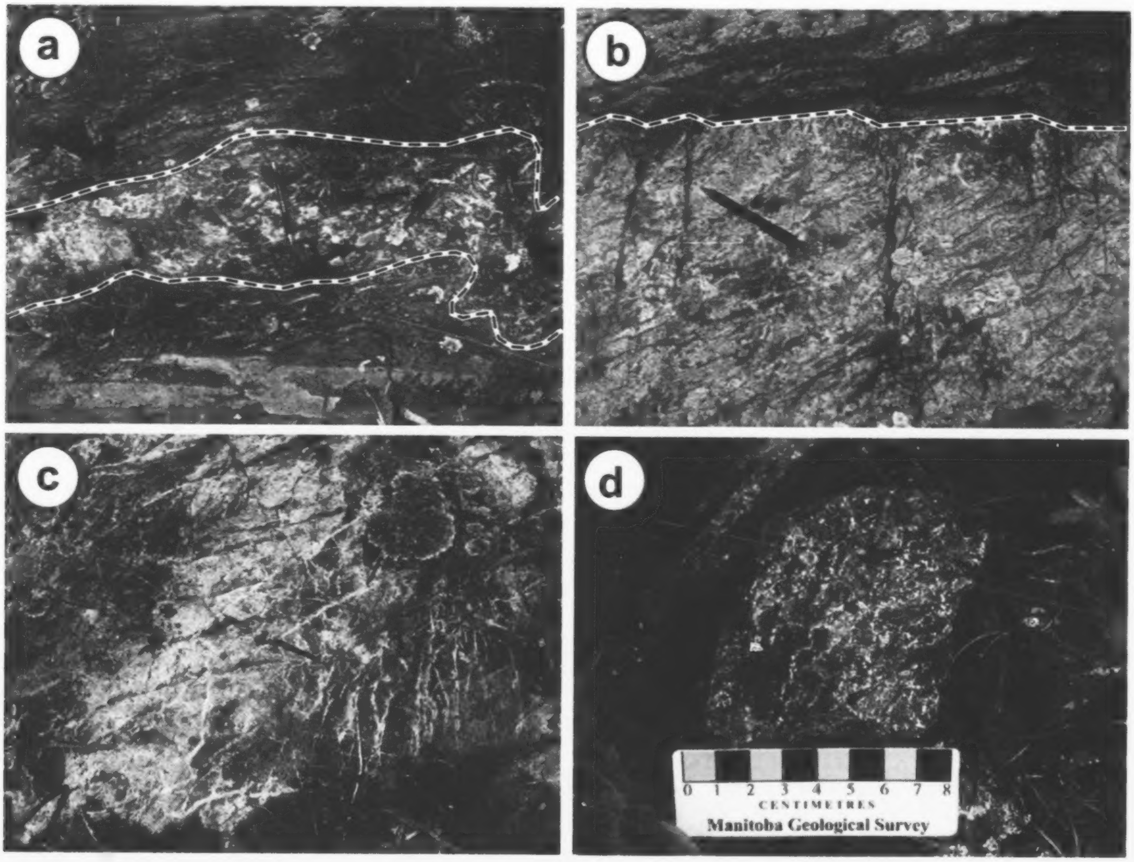

Figure GS-11-7: *Outcrop photographs of mineralization in the Lily Lake area, southeastern Rice Lake greenstone belt:* ***a)*** *shear-hosted quartz-arsenopyrite vein (outlined), north of Lily Lake;* ***b)*** *patchy, intense silica-arsenopyrite alteration associated with discordant fault (sharp slip surface indicated by dashed line), southwest of Gem Lake;* ***c)*** *quartz-vein stockwork and hydrothermal breccia, Normandy Lake; d) sulphidized iron formation, southwest of Lily Lake.*

hydrothermal breccia and peripheral stockwork quartz-vein arrays define a 200 m thick zone that can be traced on surface for at least 800 m along strike (Figure GS-11-7c). This zone is situated in the immediate hangingwall of a strongly sheared and faulted, northwest-trending contact between pillowed basalt flows (unit 4a) and greywacke-mudstone turbidite (unit 1c), which evidently served as a conduit for focused, high-volume discharge of hydrothermal fluids.

Sulphidized iron formation

In 2007, the MGS also identified a new gold occurrence south of Lily Lake and approximately 300 m west-southwest of the main Beaver Gold occurrence. The occurrence is hosted by a northwest-trending unit of interstratified quartz greywacke and polymictic conglomerate (unit 2b), approximately 10 m stratigraphically below the contact with an overlying unit of mafic tectonite (unit 4c). The hostrocks to the occurrence consist of a 3–4 m thick unit of magnetite iron formation that can be traced discontinuously along strike for 80 m. At the occurrence, the iron formation appears to abruptly terminate, perhaps indicating the presence of a crosscutting fault. Here, the iron formation is strongly silicified and chloritized, and contains up to 30% pyrite and arsenopyrite; quartz veins are absent (Figure GS-11-7d). The pyrite is coarsely crystalline and occurs as irregular veinlets and disseminations, whereas the arsenopyrite is very fine grained and forms near-solid blebs and disseminations. Hand-specimens are nonmagnetic, suggesting complete replacement of primary magnetite. A grab sample of this material returned 3550 ppb Au and 20 200 ppm As, with negligible Ag and base metals. The style and setting of this mineralization, coupled with the high Au:Ag ratio, are indicative of epigenetic, as opposed to syngenetic (i.e., stratiform), iron formation–hosted gold deposits (e.g., Kerswill, 1996). The stratabound disseminated arsenopyrite mineralization described at the Gem South occurrence is also suggestive of this deposit type.

In 1977, Rock Ore Exploration and Development Ltd. completed one diamond-drill hole (47-4-77) approximately 100 m along strike to the west of the new gold showing to test a weak EM conductor for massive base-metal–sulphide mineralization. Although the drill logs indicate several intervals of favourable alteration, quartz veining and disseminated sulphide mineralization, only two narrow intervals were sampled for gold assay (with negligible results).

Economic considerations

Gold occurrences in the Lily Lake area are hosted by a distinctive association of rock types that includes magnetite iron formation, tonalite-clast conglomerate, mafic volcanic rocks and quartz greywacke. Although this association is regionally extensive along the southern margin of the Rice Lake greenstone belt, the most significant gold occurrences are spatially associated with the west-trending Lily–Banksian deformation corridor, which disrupts the stratigraphic succession and records progressive dextral shearing and folding during late-orogenic transcurrent deformation. In terms of stratigraphic and structural setting, and style of mineralization, these occurrences are strongly analogous to epigenetic gold deposits in the Neoarchean Beardmore-Geraldton greenstone belt of the Superior Province (e.g., Lafrance et al., 2004) and the Neoarchean Rankin Inlet greenstone belt of the Hearne Province (i.e., the 'Meliadine Trend'; *see* Carpenter and Duke, 2004). In both these belts, significant gold deposits are situated along a regional-scale interface between mafic metavolcanic rocks and metasedimentary rocks, and are hosted by chemically favourable rock types (principally iron formation) in areas of structural complexity resulting from discordant shears, folds or faults, or sheared lithological contacts. In this regard, future exploration in the Lily Lake area should be focused on delineating areas of structural complexity along and within the laterally extensive iron formation and mafic tectonite units identified in this study, utilizing detailed geological mapping and magnetometer surveys. As described by D. Busch (A.F. 94538, 94541), the sharply truncated and tightly folded iron formations indicated by magnetometer data at Lily Lake represent obvious exploration targets. Similar sites of favourable chemistry and structure also exist along the Manigotagan River between Lily Lake and Banksian Lake.

Also noteworthy is the fact that the regional tectonic setting and lithostratigraphy of the Lily Lake area are substantially similar to those in the area of the Éléonore property in the James Bay district of Quebec. Here, the approximately 2.76 million ounce Roberto gold deposit (Goldcorp Inc., 2007) occurs in metasedimentary rocks of the Opinaca Subprovince, near the interface with the mainly metavolcanic La Grande Subprovince, in a setting that is analogous to the English River–Uchi interface in Manitoba. The hostrocks consist of thin-bedded turbiditic greywacke and minor polymictic conglomerate that, in the footwall of the deposit, contain abundant aluminosilicate mineralization and are intruded by numerous sill-like diorite intrusions. The auriferous zones consist of 2–5% arsenopyrite and pyrrhotite associated with transposed, stratabound, stockwork quartz veins and proximal quartz-actinolite-microcline-tourmaline alteration. Although the genesis of this deposit remains poorly understood, the Éléonore exploration model emphasizes the association of greywacke turbidite, diorite intrusions and aluminosilicate mineralization. Based on the regional mapping of McRitchie and Weber (1971), there appears to be several areas in the English River Subprovince in which these attributes coincide.

Acknowledgments

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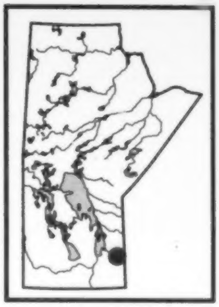
GS-12 Stratigraphic investigations in the Bird River greenstone belt, Manitoba (part of NTS 52L5, 6)

by H.P. Gilbert



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Summary

The results of detailed stratigraphic mapping and concurrent geochemical and geochronological investigations in the Neoarchean Bird River greenstone belt are now compiled and form the basis of a revised stratigraphic framework that builds on the work of previous authors. The predominant arc-type rocks of the Bird River Belt (BRB) are tectonically distinct from flanking, older, back-arc–type basaltic sequences (Lamprey Falls Formation) that are probably associated with early arc rifting. The Lamprey Falls Formation is intruded by the Bird River Sill (2.745 Ma), which hosts base-metal and platinum-group-element (PGE) mineralization. Arc-type rocks in the BRB (ca. 2.73 Ma) are separated into northern and southern structural panels by an elongate formation of fault-bounded turbidites (Booster Lake Formation). Fluvial-alluvial sedimentary rocks (Flanders Lake Formation) overlie the arc volcanic strata at the east end of the BRB. Detrital zircon data suggest that both the turbidites and the fluvial-alluvial sedimentary rocks postdate the arc-type sequence by 10–20 Ma. The arc-type north panel consists of a diverse sequence of sedimentary and volcanic rocks ('diverse arc assemblage') that appear to underlie a more homogeneous section of calcalkaline dacite and rhyolite (Peterson Creek Formation). Mafic to felsic arc volcanic rocks of the south panel (Bernic Lake Formation), which are slightly younger than the north panel rocks, are tholeiitic and include both normal and geochemically more evolved types. Contacts between these lithologically and geochemically distinct panels are typically faulted.

Base-metal mineralization prospects in the BRB include both magmatic types and stratigraphically associated occurrences. The magmatic type is exemplified by the Maskwa deposit, located within the basal part of the Bird River Sill. Stratigraphically associated mineralization includes a variety of occurrences that are located either at lithological contacts (e.g., at the margins of basaltic units or within iron formations) or within stratigraphic members, such as felsic volcanic rocks of the Bernic Lake Formation and basalt of the Lamprey Falls Formation.

Introduction

A geological mapping program was initiated by the Manitoba Geological Survey (MGS) in 2005 in the Bird River greenstone belt of southeastern Manitoba (Figure GS-12-1). Concurrent with detailed mapping by the author, several undergraduate and graduate research projects were initiated to conduct thematic studies on both regional tectonic aspects and localized topics related to the economic geology of the area. At this time, M.Sc. projects by C. Mealin and P. Kremer at the University of Waterloo, which focused on the geology of the PGE-bearing Bird River Sill and the setting of rare-element-bearing pegmatite bodies, respectively, are close to completion. A post-doctoral research project on the tectonic setting and history of the Bird River area by M. Duguet (GS-13, this volume) will be concluded by mid-2008.

Stratigraphic mapping and related geochemical investigations by the author in the eastern part of the Bird River Belt (BRB) were initiated in 2005 and completed during the summer of 2006, coincident with a western extension of geological mapping (Gilbert, 2006a). Fieldwork in 2007 focused on the north half of the greenstone belt in the area between Bird Lake and Lac du Bonnet (Figure GS-12-2). This detailed mapping, together with the results of geochemical and geochronological investigations, has led to the revised stratigraphic framework for the BRB presented in this report. Mapping in the southwestern part of the greenstone belt planned for 2008 will represent the last phase of the Bird River Project.

Previous work and current exploration

Mineral exploration and geological investigations in the Bird River area span the past century, dating from the pioneering work of Tyrrell (1900). Economic interest in the region has focused largely on two resource types: rare-element–bearing pegmatite bodies and mafic to ultramafic intrusive rocks containing base metals and PGE (Gilbert, 2006b). Investigation of a Cr showing on the Bird River in 1942 led to the discovery of a base-metal ore deposit at the north margin of the Bird River Sill, where Cu and Ni were produced for a decade until the mid-1970s at the Maskwa-Dumbarton mine (Figure GS-12-2). Feasibility studies are currently underway with the aim of reopening a new mine at Maskwa that will extract more than 9 million tons of ore over a period of 8 years (Mustang Minerals Corp., 2007). In addition, Marathon PGM Corporation is prospecting for base metals and PGE in the vicinity of the Bird River Sill, on ground formerly held by Gossan Resources Ltd. (Marathon PGM Corporation, 2007). Current exploration also includes ongoing investigations for new sources of rare elements in settings similar to that of the Tanco pegmatite.

The first systematic geological mapping of the BRB

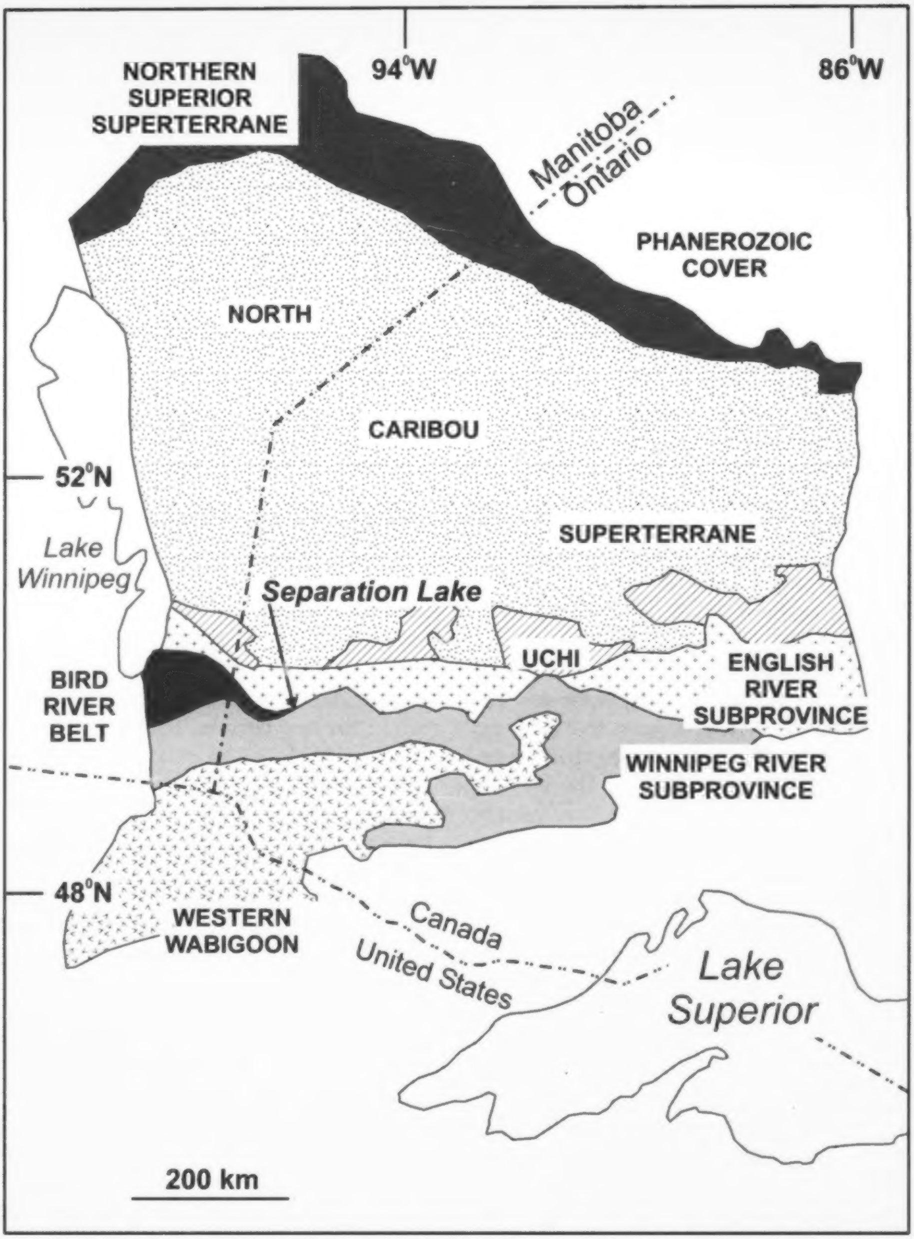

NORTHERN SUPERIOR SUPERTERRANE
94°W
86°W
Manitoba
Ontario
PHANEROZOIC COVER
NORTH
CARIBOU
SUPERTERRANE
52°N
Lake Winnipeg
Separation Lake
UCHI
ENGLISH RIVER SUBPROVINCE
BIRD RIVER BELT
WINNIPEG RIVER SUBPROVINCE
48°N
WESTERN WABIGOON
Canada
United States
Lake Superior
200 km

Figure GS-12-1: *Simplified geology of the western Superior Province, showing the location of the Bird River Belt.*

was undertaken more than 50 years ago (Springer, 1948; Davies, 1952). Geological investigations were subsequently carried out by Trueman (1971), who completed a study of the Bird River Sill, and by Theyer (1981), Scoates (1983) and Scoates et al. (1987). The Bird River greenstone belt was mapped by Trueman (1980) as a Ph.D. thesis. Cerny et al. (1981) provided a comprehensive study of the abundant pegmatite intrusions of the region, as well as a synthesis and interpretation of the regional geology. Prior to the current project, the most recent compilation of the geology of the area consisted of a Manitoba Geological Survey 1:250 000 scale geological map (Manitoba Energy and Mines, 1987).

Regional setting

The Neoarchean BRB is located between the English River and Winnipeg River subprovinces in the southwestern part of the Superior Province (Figure GS-12-1). The BRB is part of a 150 km long, east-trending supracrustal belt that extends east to Separation Lake in Ontario. The

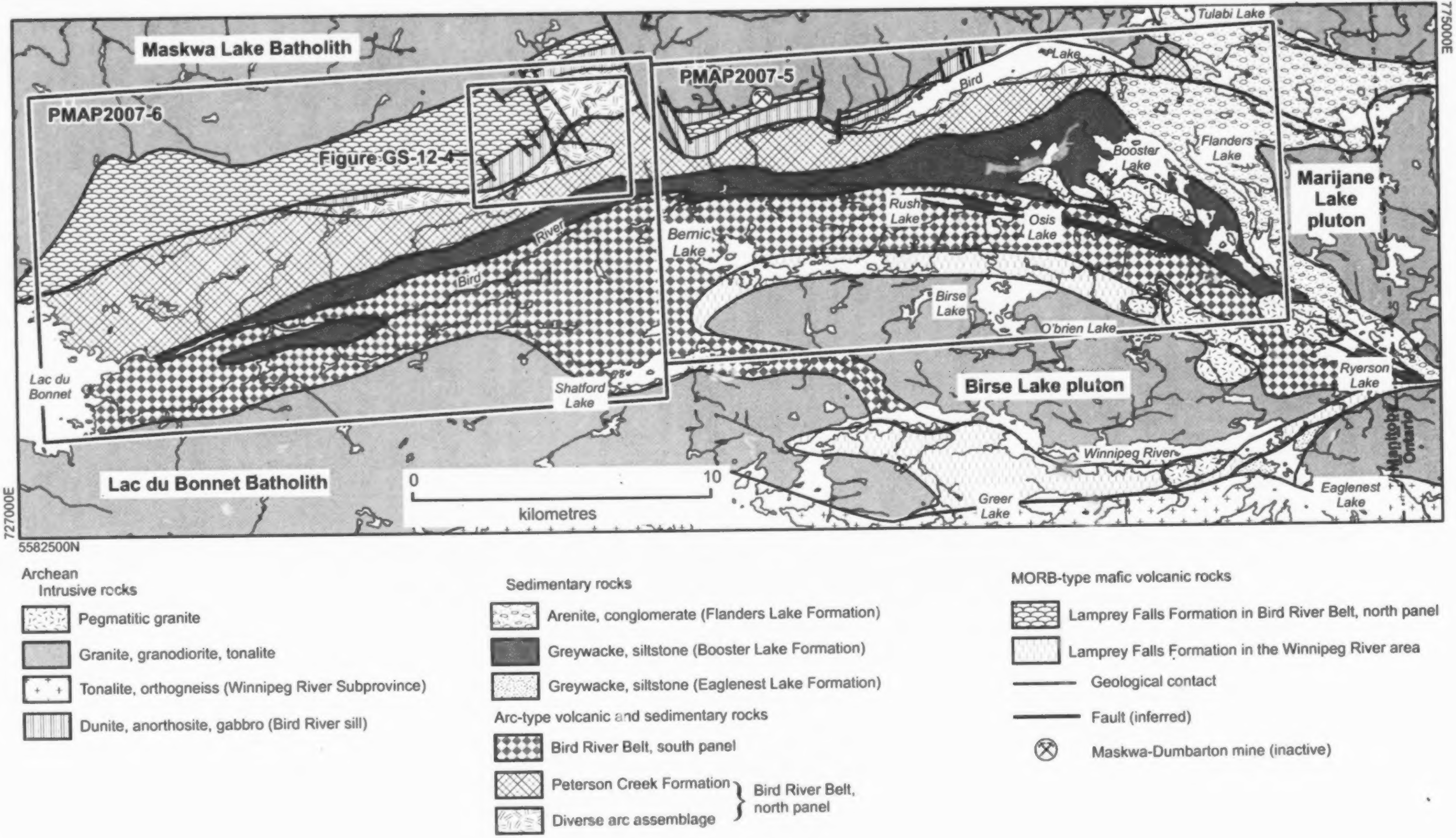

5600000N
775000E
Tulabi Lake
Maskwa Lake Batholith
PMAP2007-5
PMAP2007-6
Figure GS-12-4
Bird
Lake
Booster Lake
Flanders Lake
Marijane Lake pluton
Rush Lake
Osis Lake
Bernic Lake
River
Bird
Birse Lake
O'brien Lake
Lac du Bonnet
Shatford Lake
Birse Lake pluton
Ryerson Lake
Winnipeg River
Manitoba
Ontario
Lac du Bonnet Batholith
0
10
kilometres
Eaglenest Lake
Greer Lake
727000E
5582500N
Archean
Intrusive rocks
Pegmatitic granite
Granite, granodiorite, tonalite
Tonalite, orthogneiss (Winnipeg River Subprovince)
Dunite, anorthosite, gabbro (Bird River sill)
Sedimentary rocks
Arenite, conglomerate (Flanders Lake Formation)
Greywacke, siltstone (Booster Lake Formation)
Greywacke, siltstone (Eaglenest Lake Formation)
Arc-type volcanic and sedimentary rocks
Bird River Belt, south panel
Peterson Creek Formation
Diverse arc assemblage
Bird River Belt, north panel
MORB-type mafic volcanic rocks
Lamprey Falls Formation in Bird River Belt, north panel
Lamprey Falls Formation in the Winnipeg River area
Geological contact
Fault (inferred)
Maskwa-Dumbarton mine (inactive)

***Figure GS-12-2:** Generalized geology of the Bird River Belt.*

oldest known rocks in the BRB are mid-ocean-ridge basalt (MORB)–like, back-arc volcanic sequences (Lamprey Falls Formation) along the north and south flanks of the central part of the belt. The latter consists predominantly of ca. 2.73 Ma arc volcanic rocks (Gilbert, 2006b). The greenstone belt is separated into north and south structural panels by a fault-bounded, east-trending turbidite sequence (Booster Lake Formation, 2.712 ±17 Ma; Gilbert, 2006b; Figure GS-12-2). Fluvial-alluvial sedimentary rocks of similar age (Flanders Lake Formation, 2.697 ±18 Ma; Gilbert, 2006b) overlie the arc volcanic strata at the east end of the BRB. Turbidite and fluvial-alluvial sedimentary rocks to the north in the English River Subprovince are similar in depositional age and may be stratigraphically equivalent to the Booster Lake and Flanders Lake formations (Gilbert, 2007a).

Stratigraphy

Arc-type rocks of the north and south panels of the BRB are geochemically distinct (Gilbert, 2007a) and separated in age by approximately 6 Ma (M. Duguet and D.W. Davis, pers. comm., 2006; P. Kremer and D.W. Davis, pers. comm., 2006; Table GS-12-1). Consequently, a given lithostratigraphic unit cannot occur in both the north and south panels, as had been proposed by Cerny et al. (1981). The revised stratigraphy of the BRB proposed here consists of six main supracrustal formations, described in order of decreasing age:

- 'Lamprey Falls Formation' (predating the 2.745 Ma Bird River Sill; Wang, 1993) consists almost entirely of N-MORB–type, back-arc basaltic rocks and associated gabbro. These rocks occur along the margins of both the north and south structural panels of the BRB, flanking the arc-type rocks that constitute the main part of the belt (Gilbert, 2006b). The N-MORB–type sequence in the south is subdivided into two panels that wrap around the granitoid Birse Lake pluton in the area between Birse Lake and the Winnipeg River (Figure GS-12-2; Gilbert, 2007b).
- 'Diverse arc assemblage' encompasses a variety of calcalkaline arc-type rocks in the north panel that include mafic to felsic volcanic flows, volcaniclastic and epiclastic rocks (commonly reworked by subaqueous mass flows), and minor chert and iron formation.
- 'Peterson Creek Formation' (2.731.1 ±1 Ma; M. Duguet and D.W. Davis, pers. comm., 2006) is a calcalkaline sequence of massive and fragmental dacite, rhyolite and volcaniclastic rocks within the north panel that is interpreted to overlie the diverse arc assemblage.
- 'Bernic Lake Formation' (2.724.6 ±1.1 Ma; P. Kremer and D.W. Davis, pers. comm., 2006) consists of all arc-type volcanic rocks that occur within the tholeiitic south panel of the belt.
- 'Booster Lake Formation' (2.712 ±17 Ma; Gilbert, 2006b) is a sequence of turbiditic greywacke and siltstone.
- 'Flanders Lake Formation' (2.697 ±18 Ma; Gilbert, 2006b) is a fluvial-alluvial sedimentary sequence. Detrital zircon analysis suggests the Booster Lake and Flanders Lake formations contain detritus eroded from both the BRB and the flanking granitoid terranes (Gilbert, 2006b).

Lamprey Falls Formation

Lithological details of the N-MORB–type basalt and subordinate, intercalated iron formation in the Lamprey Falls Formation have been described previously (Duguet at al., 2006; Gilbert, 2006b). New data from mapping in 2007 are summarized as follows:

- Synvolcanic gabbro is subordinate to basalt in the Lamprey Falls Formation south of the greenstone belt, whereas gabbro is more conspicuous at the north flank of the BRB. Meso- to melanocratic gabbro constitutes 30–90% of the Lamprey Falls Formation over a width of 2 km in the area northwest of the Bird River Sill (Gilbert, 2007c).
- The aphyric pillowed flows along the north flank of the BRB are predominantly south facing and locally characterized by thick interpillow masses of hyaloclastic tuff (Figure GS-12-3a). At least one pillowed unit of plagioclase-megaphyric basalt (>70 m thick) is interlayered with these aphyric flows (Figure GS-12-3b).
- Minor felsic volcanic rock units occur within the Lamprey Falls Formation basaltic sequences along both the north and south flanks of the BRB.
- A major, early fold structure in the Lamprey Falls Formation is defined by variable basaltic flow trends in the area northwest of the Bird River Sill (Gilbert, 2007c). This steeply southeast-plunging, regional open fold appears to predate emplacement of the Bird River Sill.

Diverse arc assemblage

The diverse arc assemblage, with an estimated true thickness of 750 m, extends laterally through the BRB north panel for at least 24 km, from the east end of Bird Lake to the area west of the junction of Provincial Roads (PR) 314 and 315. To the north, the assemblage is assumed to be in fault contact with the Lamprey Falls Formation, whereas its contact with the Peterson Creek Formation to the south is interpreted as either conformable or disconformable.

The widest and most complete sequence of arc-type rocks within the BRB north panel occurs in the central part of the greenstone belt, near the junction of PR 314 and 315 (Figure GS-12-4; Figure GS-12-5; 'Highway Junction section' *in* Gilbert, 2006b). The main part of this section is south facing and monoclinal, but localized folding occurs in the north part and an east-trending

Table GS-12-1: Geological formations in the Bird River Belt.

Late intrusive rocks

Granite, pegmatite, granodiorite, tonalite, quartz diorite

(Marijane Lake pluton, **2645.6 ±1.3 Ma**(1); Lac du Bonnet batholith, **2660 ±3 Ma**(2); Birse Lake pluton, **2723.2 ±0.7 Ma**(3))

Sedimentary rocks

FLANDERS LAKE FORMATION (**2697 ±18 Ma**(4))

Lithic arenite, polymictic conglomerate

=== ***Fault, inferred*** ===

BOOSTER LAKE FORMATION (**2712 ±17 Ma**(4))

Greywacke-siltstone turbidite, conglomerate

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ ***Unconformity, inferred*** ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

Intrusive rocks

MISCELLANEOUS INTRUSIONS

Gabbro, diorite, quartz-feldspar porphyry; granodiorite

(Maskwa Lake batholith II, **2725 ±6 Ma**(2); Pointe du Bois batholith, **2729 ±8.7 Ma**(2))

Metavolcanic and metasedimentary rocks

BERNIC LAKE FORMATION (**2724.6 ±1.1 Ma**(3))

Basalt, andesite, dacite and rhyolite (massive to fragmental); related intrusive rocks and heterolithic volcanic fragmental rocks

PETERSON CREEK FORMATION (**2731.1 ±1 Ma**(1))

Dacite, rhyolite (massive to fragmental); felsic tuff and heterolithic felsic volcanic fragmental rocks

DIVERSE ARC ASSEMBLAGE

Basalt, andesite, rhyolite, related fragmental and intrusive rocks; heterolithic volcanic fragmental rocks; greywacke-siltstone turbidite, chert, iron-formation; polymictic conglomerate (contains clasts derived from Bird River Sill)

~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ ***Unconformity, inferred*** ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~

Intrusive rocks

BIRD RIVER SILL (**2744.7 ±5.2 Ma**(2))

Dunite, peridotite, picrite, anorthosite and gabbro

=== ***Fault, inferred*** ===

Metavolcanic and metasedimentary rocks

LAMPREY FALLS FORMATION

Basalt (aphyric to plagioclase-phyric; locally pillowed, amygdaloidal or megacrystic); related volcanic breccia; oxide-facies iron formation

=== ***Fault, inferred*** ===

EAGLENEST LAKE FORMATION

Greywacke-siltstone turbidite

Older intrusive rocks

Granodiorite, diorite (Maskwa Lake batholith I, **2782 ±11 Ma**, **2844 ±12 Ma**(2))

References for geochronological data:

(1) M. Duguet and D.W. Davis (pers. comm., 2006)

(2) Wang (1993)

(3) P. Kremer and D.W. Davis (pers. comm., 2006)

(4) Gilbert (2006b)

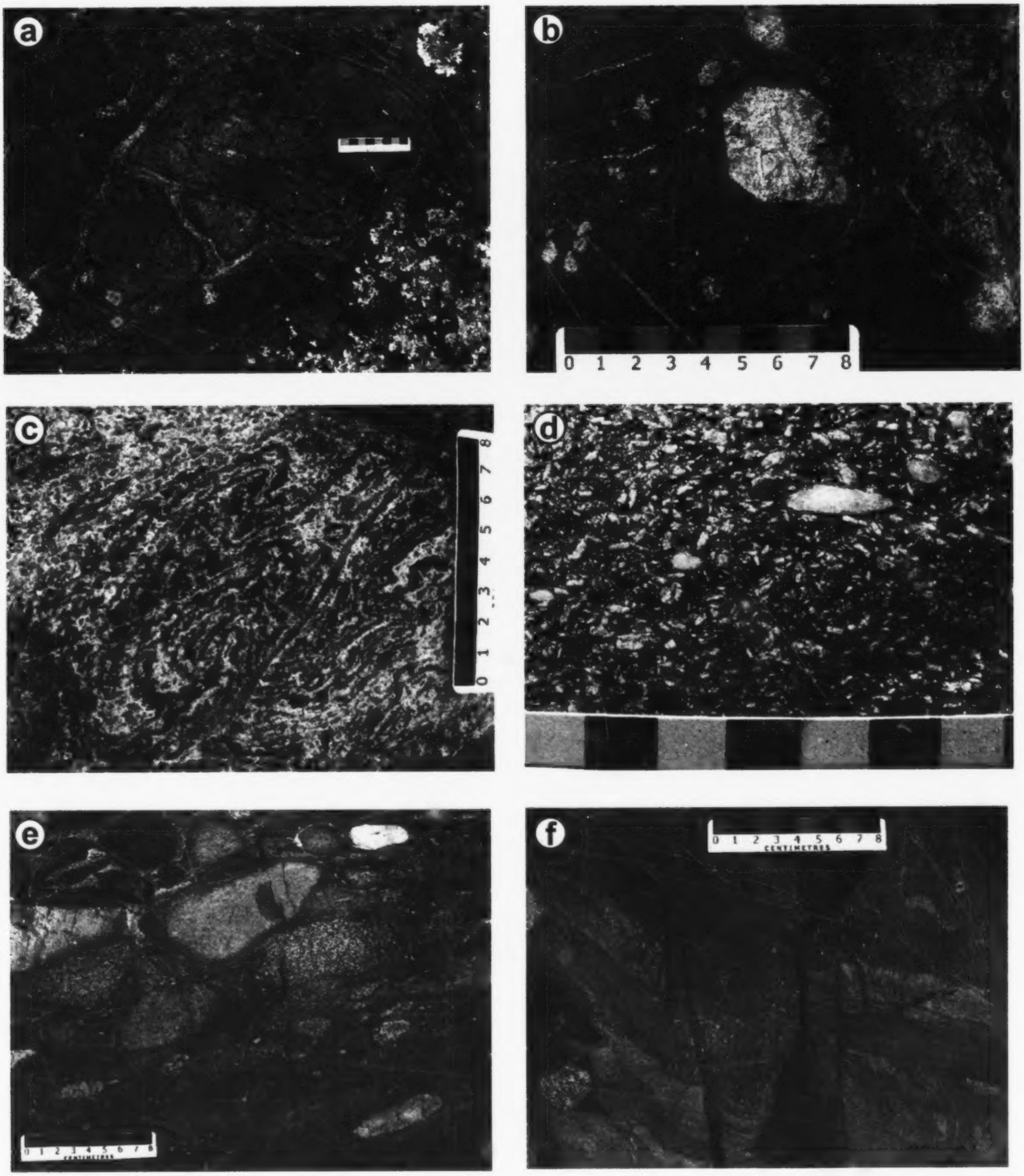


Figure GS-12-3: *Outcrop photographs of volcanic and epiclastic rocks in the north panel of the BRB:* ***a)*** *aphyric pillowed basalt with interpillow hyaloclastite, Lamprey Falls Formation (UTM 318769E, 5593392N);* ***b)*** *plagioclase-megaphyric pillowed basalt, Lamprey Falls Formation (UTM 318638E, 5593286N);* ***c)*** *spherulitic rhyolite flow with contorted flow lamination, diverse arc assemblage (UTM 319853E, 5594930N);* ***d)*** *plagioclase-hornblende–phyric basalt with quartz amygdules, diverse arc assemblage (UTM 302808E, 5586144N);* ***e)*** *polymictic conglomerate with mainly basalt and gabbro clasts, diverse arc assemblage (UTM 320494E, 5592734N);* ***f)*** *greywacke-siltstone turbidite showing graded bedding, scour and synsedimentary deformation of bedding, diverse arc assemblage, close to the axial trace of the* D_1 *anticline in Figure GS-12-4 (UTM 320596E, 559279N); the plane of fragment flattening (parallel to* S_1*) is approximately normal to bedding.*

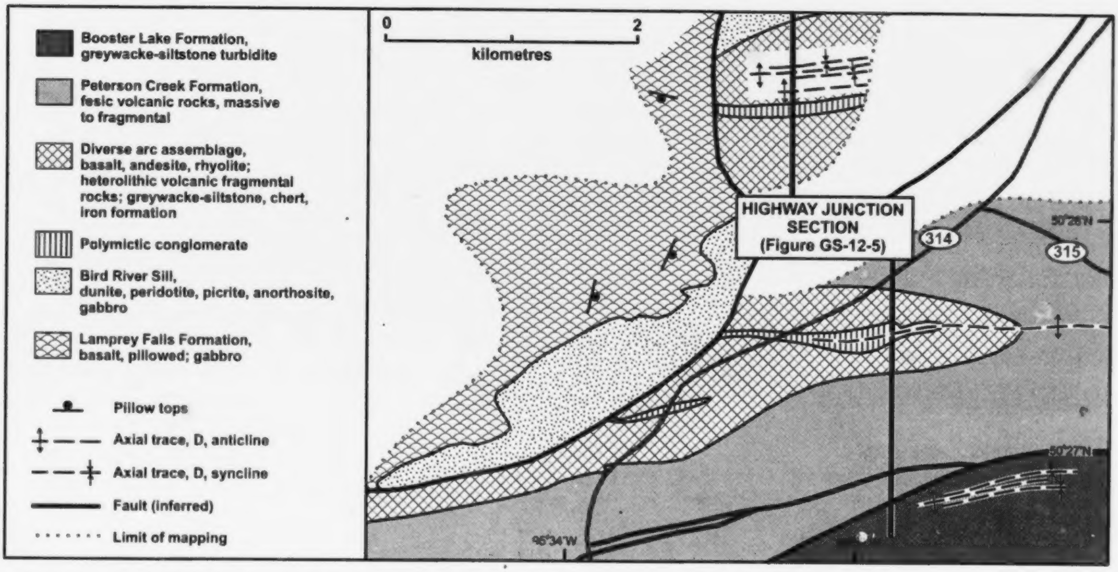

Booster Lake Formation, greywacke-siltstone turbidite
Peterson Creek Formation, fesic volcanic rocks, massive to fragmental
Diverse arc assemblage, basalt, andesite, rhyolite; heterolithic volcanic fragmental rocks; greywacke-siltstone, chert, iron formation
Polymictic conglomerate
Bird River Sill, dunite, peridotite, picrite, anorthosite, gabbro
Lamprey Falls Formation, basalt, pillowed; gabbro
Pillow tops
Axial trace, D, anticline
Axial trace, D, syncline
Fault (inferred)
Limit of mapping
0
2
kilometres
HIGHWAY JUNCTION SECTION (Figure GS-12-5)
314
315
50°28'N
50°27'N
95°34'W

***Figure GS-12-4:** Geology west of the junction of Provincial Roads 314 and 315, north panel, Bird River Belt.*

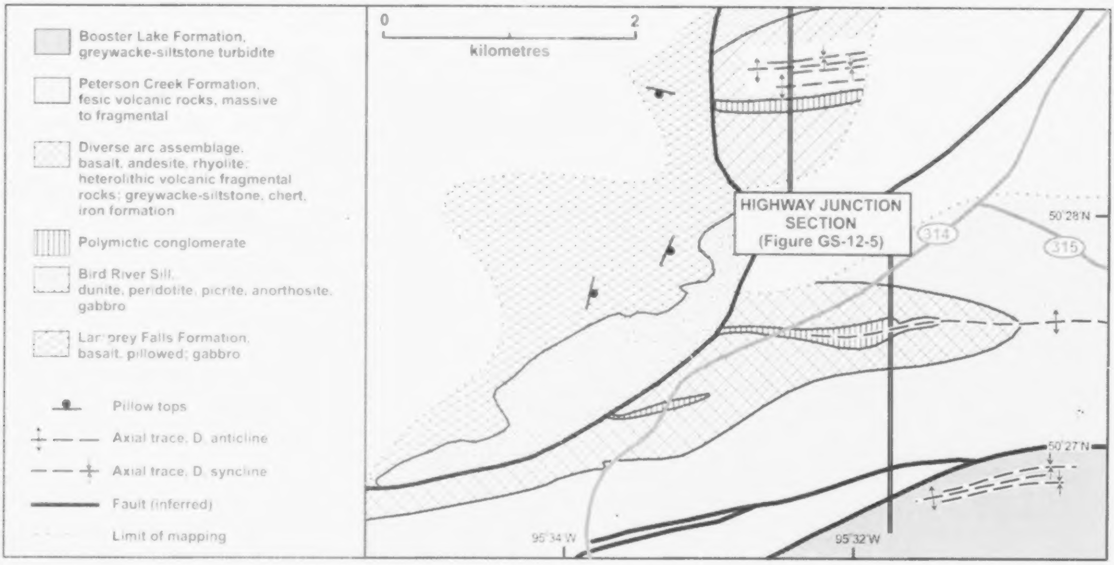
anticlinal fold occurs farther to the south. The lower part of the stratigraphic sequence consists of a wide variety of volcanic flows, associated fragmental rocks and sedimentary deposits (Figure GS-12-3c, d) that are overlain by a polymictic conglomerate unit at least 75 m thick (unit '7W' *in* Gilbert, 2006b). This stratigraphic marker unit also occurs at a locality 2 km farther south (Figure GS-12-3e), in the core of the east-trending anticline. Overlying the conglomerate, the upper part of the diverse arc assemblage consists of turbidite (Figure GS-12-3f) and volcanic fragmental rocks (Figure GS-12-6a) that are variously reworked by mass flows, as well as aphyric, quartz-amygdaloidal andesite.

Lithological units of the diverse arc assemblage are described in Gilbert (2006b, c). The following brief synopsis of the stratigraphic sequence includes data from recent (2007) mapping. The lower, 0.65 km wide part of the diverse arc assemblage contains a variety of rock types that indicate phases of rapid sedimentation (turbidites and debris flows), interspersed with relatively quiescent volcanic exhalative activity characterized by chert units and the accumulation of felsic and mafic tuffs, as well as extrusive felsic and mafic volcanic flows. The polymictic conglomerate unit that overlies the lower part of the sequence consists mainly of unsorted basalt, gabbro and subordinate rhyolite, greywacke-siltstone and chert clasts. Sporadic fragments of very coarse grained anorthositic gabbro are likely derived from the Bird River Sill (Figure GS-12-6b), whereas volcanic and sedimentary clasts are probably derived from the lower part of the diverse arc assemblage, as well as the Lamprey Falls Formation. Relative uplift of the source terrane may have been due to extensional faulting, followed by erosion and the subsequent accumulation of coarse detritus as a littoral or fluvial-fan deposit. Andesitic flows and volcanic fragmental and epiclastic rocks in the upper part of the sequence, which overlie the polymictic conglomerate, document a resumption of volcanism associated with the deposition of mass flows and turbidites (Figure GS-12-5).

Peterson Creek Formation

The Peterson Creek Formation extends the entire length of the BRB north panel, from the shore of Lac du Bonnet in the west to Bird Lake in the east, for a total strike length of approximately 40 km (Figure GS-12-2). The maximum width of the formation is 2.7 km, but the true thickness may be less because of possible structural repetition. Stratigraphic interpretation of the Peterson Creek Formation is hampered by an absence of top indicators, but the recurrence of several distinctive rock types in different parts of across-strike sections is suggestive of structural repetition, due to either folding or major faults. One such structure is an east-northeast–trending shear zone (Figure GS-12-6c) that is locally coincident with Peterson Creek in the area southwest of the junction of PR 314 and 315 (Gilbert, 2007c). The north margin of the Peterson Creek Formation appears to be conformable or disconformable with the diverse arc assemblage, whereas the south margin is sheared and mylonitized close to the faulted contact with the Booster Lake Formation (Figure GS-12-4).

Massive, dacitic and rhyolitic rocks are predominant in the Peterson Creek Formation and include both aphyric and (equally abundant) plagioclase±quartz–phyric types. Aphyric felsic volcanic flows commonly display anastomosing thermal-contraction fractures or domains of *in situ* brecciation that are gradational with autoclastic breccia.


Booster Lake Formation, greywacke-siltstone turbidite
Peterson Creek Formation, fesic volcanic rocks, massive to fragmental
Diverse arc assemblage, basalt, andesite, rhyolite; heterolithic volcanic fragmental rocks; greywacke-siltstone, chert, iron formation
Polymictic conglomerate
Bird River Sill, dunite, peridotite, picrite, anorthosite, gabbro
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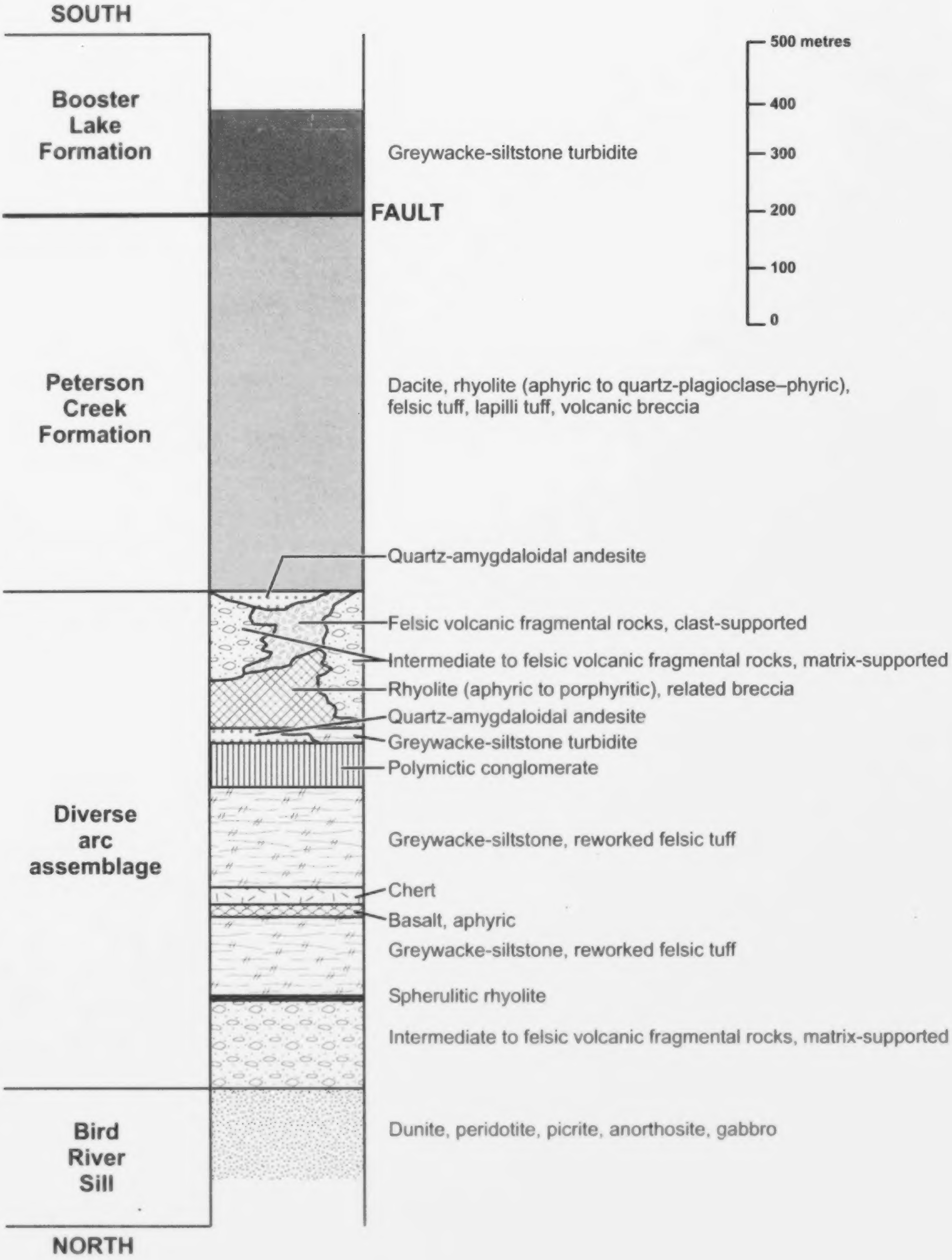
SOUTH
Booster Lake Formation
Greywacke-siltstone turbidite
FAULT
500 metres
400
300
200
100
0
Peterson Creek Formation
Dacite, rhyolite (aphyric to quartz-plagioclase–phyric), felsic tuff, lapilli tuff, volcanic breccia
Quartz-amygdaloidal andesite
Felsic volcanic fragmental rocks, clast-supported
Intermediate to felsic volcanic fragmental rocks, matrix-supported
Rhyolite (aphyric to porphyritic), related breccia
Quartz-amygdaloidal andesite
Greywacke-siltstone turbidite
Polymictic conglomerate
Diverse arc assemblage
Greywacke-siltstone, reworked felsic tuff
Chert
Basalt, aphyric
Greywacke-siltstone, reworked felsic tuff
Spherulitic rhyolite
Intermediate to felsic volcanic fragmental rocks, matrix-supported
Bird River Sill
Dunite, peridotite, picrite, anorthosite, gabbro
NORTH

Figure GS-12-5: *Stratigraphic column of the Highway Junction section, showing lithostratigraphic details of the diverse arc assemblage, north panel, Bird River Belt.*

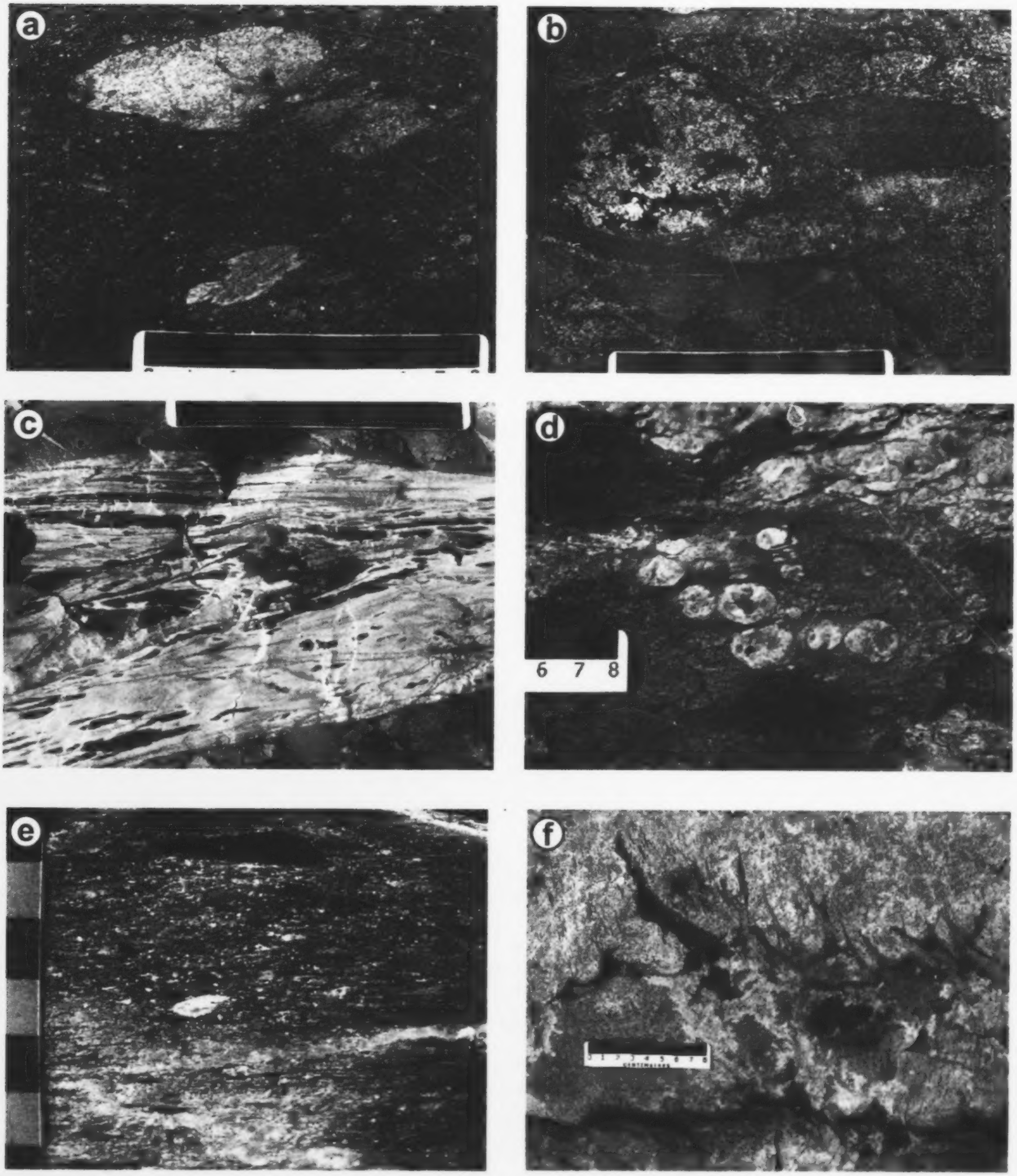

***Figure GS-12-6:** Outcrop photographs of volcanic and epiclastic rocks in the north panel of the BRB: **a)** heterolithic volcanic breccia with mainly felsic and intermediate fragments, interpreted as a reworked mass-flow deposit, diverse arc assemblage (UTM 320714E, 5592814N); **b)** polymictic conglomerate with pebble of anorthositic gabbro, probably derived from the Bird River Sill, diverse arc assemblage (UTM 320520E, 5592649N); **c)** mylonitic rhyolite with disrupted quartz veins in a shear zone coincident with Peterson Creek, Peterson Creek Formation (UTM 317457E, 5590900N); **d)** spheroidal siliceous rhyolite bodies within a felsic volcanic flow, Peterson Creek Formation (UTM 320677E, 5593348N); **e)** heterolithic lapilli crystal tuff with felsic and subordinate mafic clast types, Peterson Creek Formation (UTM 316328E, 5590768N); **f)** flame structure in turbidite from the axial zone of a D_1 fold, Booster Lake Formation (UTM 318373E, 5590432N); thickly bedded greywacke and siltstone contain thin argillitic laminae; associated rip-ups are aligned parallel to S_1, normal to the bedding.*

An unusual texture in some aphyric flows consists of two separate components: spheroidal to irregularly shaped, siliceous rhyolite bodies occur within a beige-yellow, sericitic rhyolite matrix (Figure GS-12-6d). Flows of this type occur close to both the north and south margins of the Peterson Creek Formation.

Felsic tuff and subordinate, related breccia constitute approximately 30–40% of the Peterson Creek Formation in the western part of the BRB. The most abundant fragmental rock type is a heterolithic lapilli crystal tuff that contains felsic and subordinate intermediate to mafic lapilli in a (quartz-plagioclase) crystal tuff matrix (Figure GS-12-6e). These heterolithic rocks are interpreted as reworked mass-flow deposits, in contrast to rare monolithic fragmental rocks elsewhere in the Peterson Creek Formation that may be primary pyroclastic rocks.

Bernic Lake Formation

The Bernic Lake Formation is approximately 2 km wide and extends laterally for more than 45 km, from Lac du Bonnet east to the Manitoba-Ontario provincial boundary. The formation consists of calcalkaline, felsic and mafic volcanic rocks that are roughly equal in abundance in the central part of the formation, north of Birse Lake (Figure GS-12-2; Gilbert, 2007b). Farther west at Lac du Bonnet, felsic volcanic rocks are predominant; only two units of basalt occur in that part of the formation (Gilbert, 2007c).

Reconstruction of the stratigraphic sequence of the Bernic Lake Formation is hindered by deformation and alteration, as well as by a paucity of stratigraphic facing indicators. Most pillowed flows face north, consistent with the available geochemical data that indicate an overall northward direction of younging: volcanic rocks in the north part of the Bernic Lake Formation are geochemically more evolved than those in the sequence farther to the south (*see* 'Geochemistry' section).

Most of the western part of the Bernic Lake Formation remains to be mapped, but parts of the north margin, as well as a lakeshore transect of the formation at Lac du Bonnet, were examined in 2007. New data from this recent mapping are summarized as follows:

- Massive dacite-rhyolite and related breccia are major stratigraphic components in the western part of the Bernic Lake Formation. Heterolithic volcanic breccia and lapilli tuff with felsic and subordinate intermediate to mafic fragments are the other principal rock types. Rare occurrences of primary volcanic features, such as *in situ* brecciation and columnar jointing in rhyolite flows, are preserved in some units, but more typically the rocks are attenuated and altered, with localized pervasive chlorite-hornblende–rich domains. Such alteration is especially conspicuous in a zone, up to several hundred metres wide, that extends intermittently along the north margin of the formation.
- A distinctive 'iron formation', consisting of bedded carbonate, chert, greywacke-siltstone and amphibolite at least 35 m thick, extends for more than 2 km along the south shore of the Bird River where it intersects PR 314 (Gilbert, 2007c). Contact relationships of this iron formation, which occurs close to the north margin of the Bernic Lake Formation, are not exposed. The contiguous rock unit to the south of the iron formation is a felsic volcanic flow, whereas reworked felsic crystal tuff and associated rhyolitic flows occur just a few metres to the north. Pyritic mineralization occurs locally in siltstone beds and fine-grained amphibolite layers within the iron formation.
- Silicate-facies iron formation (>5 m thick) occurs at an isolated outcrop on PR 314, approximately 120 m stratigraphically south of the carbonate-chert iron formation (Gilbert, 2007c). Alternating, 0.5–12 cm thick laminae of chert, siltstone and very fine grained amphibolite are tightly folded in a shallow, west-plunging fold.
- A 170 m wide pillowed basalt unit in the south part of the Bernic Lake Formation extends east for more than 2 km from the shore of Lac du Bonnet (Gilbert, 2007c). The basalt is aphyric and plagioclase amygdaloidal, and contains sporadic minor zones of pyritic mineralization.
- A tectonic lens of pervasively mineralized heterolithic volcanic breccia is located at the contact between the Bernic Lake and Booster Lake formations, 3.5 km west of the junction between the Tanco mine road and PR 314 (Gilbert, 2007c). This fragmental unit, more than 35 m thick and 2.5 km wide along strike, is extensively iron stained and mineralized with pyrite and pyrrhotite. The volcanic breccia contains unsorted, angular to subrounded blocks (5–25 cm) of plagioclase-phyric intermediate to felsic volcanic rocks, subordinate quartz and rare mafic fragments. The east end of the mineralized fragmental unit is structurally emplaced within the Booster Lake Formation, where the fault slice extends obliquely across its bounding fault (Gilbert, 2007c).

Booster Lake Formation

Mapping in 2007 defined the western extent of the turbiditic Booster Lake Formation, a fault-bounded structural enclave that extends from the Manitoba-Ontario boundary westward through the BRB, between the north and south panels of the greenstone belt. This formation, which wedges out approximately 1 km east of the mouth of the Bird River at Lac du Bonnet (Gilbert, 2007c), has a total strike length of approximately 44 km. The estimated, maximum true thickness of this sequence in its central part is 0.7 km, although the sequence may be 1 km or more in thickness in the area immediately west of Booster Lake (Gilbert, 2007b). The structural pattern of repeated D_1 folding established at Booster Lake persists throughout the central and western parts of the formation (Gilbert, 2007b, c). Trends of the fold-axial traces are locally oblique to the faulted margins of the formation, consistent with their early (D_1) age and thus predating tectonic emplacement of the fault-bounded enclave.

A second unit of the Booster Lake Formation occurs within the northern part of the Bernic Lake Formation, just south of the Bird River (Gilbert, 2007c). The available data indicate that this tectonic enclave contains a south-facing, monoclinal turbidite sequence over 530 m thick. It is assumed to have been emplaced at the same time as a third Booster Lake fault slice that extends through Rush Lake, close to the north margin of the Bernic Lake Formation approximately 20 km farther to the east (Gilbert, 2007b). The fault slice just south of the Bird River trends east-northeast, oblique to the easterly stratigraphic trend of the Bernic Lake Formation defined by the previously described carbonate-chert iron formation.

The eastern part of the Booster Lake Formation displays a wide variety of turbidite features characteristic of classic Bouma-type sequences (Gilbert, 2005, 2006b). The 0.1–0.5 m thick cyclic units contain abundant cordierite porphyroblasts, and these occur sporadically throughout the formation farther to the west. The depositional environment of the Booster Lake sedimentary basin is interpreted to have been at an intermediate distance from the detrital source but increasingly more proximal to the west, where the cyclic turbidite units give way to more thickly bedded (0.2–2 m scale) deposits. Two facies types are recognized in the western area:

- Intercalated coarse-grained felsic wacke and subordinate siltstone, which also occurs as local rip-ups and sporadic larger rafts within the felsic wacke: These sequences, which may represent channel deposits, are characterized by normal or reverse graded bedding, scour and localized crossbedding, and are interspersed with finer grained sedimentary rocks characteristic of more quiescent periods. The texture of the felsic wacke beds, characterized by abundant subangular to subhedral detrital quartz and plagioclase grains (1–4 mm), is similar to that of some felsic volcanic rocks in the Peterson Creek Formation, suggesting the latter may have represented a local source for the turbidite deposits.
- Fine-grained greywacke beds with minor siltstone rip-ups, interlayered with subordinate siltstone and argillite (Figure GS-12-6f): These deposits are mostly unsorted but locally graded at a scale of 0.2–1 m. A high volume of detrital supply is inferred from the relatively thick beds. The depositional environment ranges between the deeper water basin farther east at Booster Lake and the higher energy environment of the coarser grained, inferred channel deposits.

Geochemistry

The main tectonic components of the Bird River Belt (BRB) — the arc-type rocks in the north and south panels and the Lamprey Falls Formation — are lithologically and geochemically distinct, and exhibit relative age differences (Duguet et al., 2006; Gilbert, 2006b, 2007a). The contrasting geochemical signatures of these components have proven particularly useful for determining their origin, tectonic environment and potential for economic mineralization. The following discussion is restricted to rocks ranging from basalt to dacite in composition; rhyolite is excluded. Four geochemically distinct volcanic rock components are identified, from oldest to youngest, as follows:

- Lamprey Falls Formation back-arc type basalt
- BRB north panel arc-type rocks (diverse arc assemblage and Peterson Creek Formation)
- Bernic Lake Formation, south part
- Bernic Lake Formation, north part

The Lamprey Falls Formation occurs along the north and south flanks of the BRB, as well as in a narrow belt between the Bernic Lake Formation and the Birse Lake pluton (Figure GS-12-2; *see* 'Stratigraphy' section). The basaltic rocks at all three localities are remarkably similar in composition (Table GS-12-2). The aphyric pillowed basalt flows and related gabbro that constitute almost the entire Lamprey Falls Formation are characterized by nearly flat N-MORB–normalized trace-element profiles (Figure GS-12-7a) in which the light rare-earth elements (REE) are slightly elevated and Th is moderately increased. Compared to arc-type rocks throughout the rest of the BRB, Lamprey Falls basalt has lower La/Yb and Zr/Y ratios, as well as lower SiO_2 content (all samples <51% SiO_2; Table GS-12-2).

Mafic to intermediate arc-type rocks in the BRB north panel are characterized by a negatively sloping trace-element profile with a pronounced Th/Nb anomaly, as well as depleted heavy REE and TiO_2 (Figure GS-12-7b). These features are typical of modern arc-type volcanic rocks. The La/Yb and Zr/Y ratios are high and the content of SiO_2 exceeds 58% in almost all BRB north panel arc-type rocks. These rocks are also characterized by a calcalkaline affinity and thus have a significantly higher Mg# than the tholeiitic rocks of the Bernic Lake Formation in the BRB south panel (Table GS-12-2; Figure GS-12-8).

Bernic Lake Formation volcanic rocks display REE patterns typical of modern arc volcanic rocks, but overall contents of these elements are elevated compared to arc-type rocks in the BRB north panel (Figure GS-12-7c, d). Average SiO_2 content (57.3%), as well as the range of SiO_2 in Bernic Lake Formation rocks are significantly lower than in the BRB north panel arc-type rocks. Heavy REE depletion relative to light REE is progressively less pronounced from BRB north panel arc-type rocks to Bernic Lake Formation south part to Bernic Lake

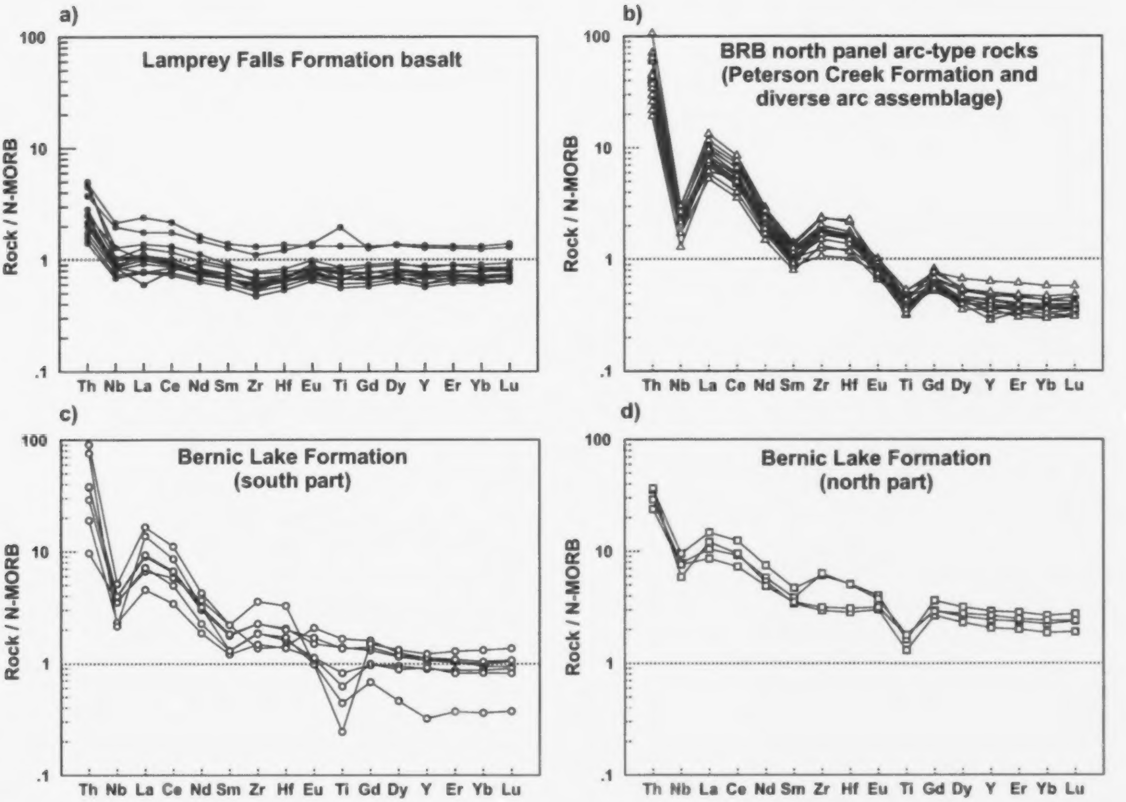

***Figure GS-12-7:** Normal mid-ocean-ridge basalt (N-MORB)–normalized extended element plots of mafic to intermediate volcanic rocks in **a)** Lamprey Falls Formation back-arc type basalt; **b)** Bird River Belt north panel arc-type rocks; **c)** Bernic Lake Formation, south part; and **d)** Bernic Lake Formation, north part. Normalizing values are after Sun and McDonough (1989).*

Formation north part rocks. The REE data indicate that the north part of the Bernic Lake Formation is relatively more evolved than the south part.

The Sm/Nd isotope data for basaltic units at different localities of the Lamprey Falls Formation support the interpretation that they are part of a single N-MORB–type volcanic suite and derived from a common source magma. The ε_{Nd} values (at 2.7 Ga) for basaltic flows in the north panel, south panel and Winnipeg River locality are +1.3, +1.8 and +1.9, respectively, and thus within analytical errors. These data further indicate that the Lamprey Falls Formation was derived from a mantle source that was relatively more juvenile and less contaminated by continental crust, compared to the source of contiguous, younger arc-type rocks. The ε_{Nd} values (at 2.7 Ga) of arc-type volcanic flows in the BRB north panel are +1 to –1.1, thus suggesting slightly more crustal contamination than in the Lamprey Falls Formation basalt. In comparison, the volcanic flows in the Bernic Lake Formation yielded ε_{Nd} values (at 2.7 Ga) between +0.7 and –2.4, indicating an increase in crustal contamination and/or recycling of older crust to the south.

Economic considerations

The north panel of the Bird River greenstone belt is the focus of ongoing base-metal and PGE exploration (see 'Previous work and current exploration' section). Marathon PGM Corporation is currently prospecting the mineralized footwall ('Page zone') of the mafic–ultramafic Bird River Sill (Marathon PGM Corporation, 2007), as well as testing geophysical anomalies within the Lamprey Falls Formation northwest of the sill, where exploration targets occur within both basaltic flows (e.g., Table GS-12-3, sample 1) and synvolcanic mafic to ultramafic intrusions. Elsewhere in the Lamprey Falls Formation, mineralized oxide-facies iron formation represents an additional setting for base-metal and possible Au mineralization (Gilbert, 2006b).

Farther south in the BRB north panel, Mustang Minerals Corp. is implementing feasibility studies for a new mine at Maskwa, targeting approximately 10 million pounds of Ni concentrate per annum, as well as other metal credits (Mustang Minerals Corp., 2007). The mineralization in the former Maskwa mine occurs within the Bird River Sill along its north margin, whereas the

Table GS-12-2: Selected analytical data for mafic to intermediate volcanic rocks in the Bird River Belt.

Rock suite		Samples	SiO_2	$SiO_{2\ range}$	FeO	MgO	TiO_2	Cr	Ni
BRB north panel arc-type rocks (diverse arc assemblage + Peterson Creek Formation)		19	59.5	56.4–68.9	5.3	3.4	0.5	112	75
BRB south panel arc-type rocks (Bernic Lake Formation)		11	57.3	45.7–68.9	11.9	2.9	1.5	38	28
Lamprey Falls Formation	BRB north panel	5	49.6	46.4–49.1	13.0	7.1	0.9	214	135
	BRB south panel at Birse Lake	4	48.3	48.5–51.2	16.9	6.5	1.5	170	113
	BRB south panel at Winnipeg River	6	49.0	48.3–49.9	13.0	7.1	0.9	268	143
Lamprey Falls Formation (average)		15	49.0	48.3–49.6	14.0	6.9	1.1	213	125

Rock suite		Samples	Zr	Nb	La	Yb	Th	$La/Yb_{(ch)}$	Zr/Y	Mg#
BRB north panel arc-type rocks (diverse arc assemblage + Peterson Creek Formation)		19	135	5.7	23.7	1.2	7.0	13.9	11.1	57
BRB south panel arc-type rocks (Bernic Lake Formation)		11	223	11.8	25.7	4.3	4.6	4.3	5.2	33
Lamprey Falls Formation	BRB north panel	5	46	2.5	2.6	2.3	0.4	0.8	2.3	53
	BRB south panel at Birse Lake	4	70	3.5	4.0	3.2	0.4	0.9	2.4	44
	BRB south panel at Winnipeg River	6	44	1.9	2.3	2.2	0.2	0.7	2.3	53
Lamprey Falls Formation (average)		15	52	2.5	2.8	2.5	0.3	0.8	2.3	50

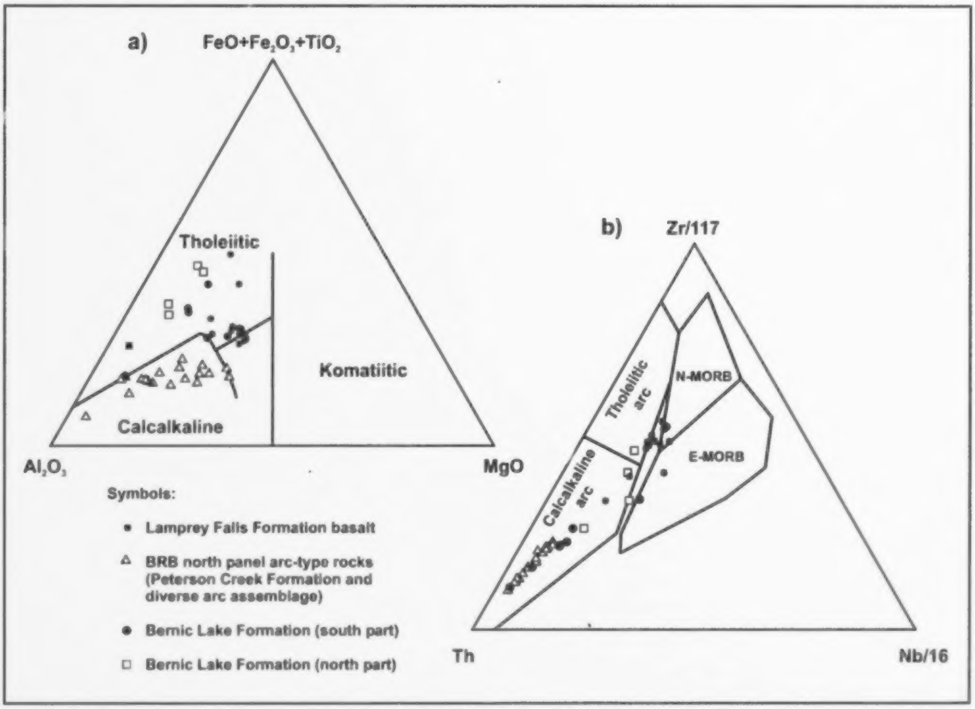

Figure GS-12-8: a) *Jensen (1976) cation plot and* ***b)*** *Th-Zr-Nb ternary diagram (Wood, 1980) of mafic to intermediate volcanic rocks in Lamprey Falls Formation; BRB north panel arc-type rocks; Bernic Lake Formation, south part; and Bernic Lake Formation, north part.*

Table GS-12-3: Selected analytical data for mineralized rocks in the Bird River Belt.

Sample number	UTM (Zone 15U, NAD 83)	Au (ppb)	Ag (ppm)	Cu (ppm)	Zn (ppm)	Pb (ppm)	Ni (ppm)	Cr (ppm)
1	318526E, 5593305N	19	0.7	1990	53	7	26	93
2	318186E, 5590502N	-	0.3	13	22	10	8	31
3	318378E, 5590432N	-	0.7	25	51	20	9	64
4	304013E, 5585512N	-	-	153	421	148	14	12
5	303025E, 5585332N	-	-	193	154	-	24	35
6	304046E, 5585991N	-	1.1	1400	68	5	191	31
7	304721E, 5586095N	-	1	262	28	6	297	14
8	310280E, 5587794N	-	0.3	23	13	3	6	17
9	302880E, 5585188N	-	0.7	38	18	16	8	88
10	302169E, 5585219N	-	1.1	160	52	1040	24	16
11	316323E, 5589487N	-	0.9	15	32	12	6	28
12	314948E, 5589410N	-	1	17	46	11	9	29
13	314434E, 5589287N	-	1	17	39	13	13	29
Analysis method		I	M/T	T	M/T	T	M/T	I

I = instrumental neutron activation analysis

M = multi-instrumental neutron activation analysis

T = total digestion with inductively coupled plasma–mass spectrometry

contiguous Ni-Cu ore deposit at the former Dumbarton mine is associated with sulphide-facies iron formation and basalt, immediately north of the sill. Mustang Minerals is also carrying out base-metal exploration in the area east of the Maskwa property ('Owyhee property'; Mustang Minerals Corp., 2007). The drill targets are associated with sulphide-facies iron formation within felsic volcanic flows of the Peterson Creek Formation (Gilbert, 2007b). A similar mineralized occurrence is located 1.3 km north of the junction of the Tanco mine road and PR 314, where a mineralized sulphide-facies iron formation is associated with rhyolite at the south margin of the Peterson Creek Formation, immediately north of the contact with the Booster Lake Formation (Gilbert, 2007c; Table GS-12-3, sample 2). A minor base-metal sulphide showing also occurs in cherty siltstone within the Booster Lake Formation, 200 m southeast of the latter occurrence (Table GS-12-3, sample 3).

In the BRB south panel (Bernic Lake Formation), sporadic conformable zones of mineralization occur in the Birse Lake area (Gilbert, 2006b). These showings are typically 0.5–1 m thick and hosted by both mafic and felsic volcanic rocks; the most conspicuous occurrence is more than 10 m wide and associated with pervasive alteration and a magnetic anomaly. Similar conformable mineralized zones with disseminated pyrite-pyrrhotite and sulphide stringers occur within the BRB south panel farther to the west (Gilbert, 2007c). The sulphides are commonly located at or close to the margins of the hostrock units, which include pillowed basalt (Table GS-12-3, sample 4) and felsic volcanic units (Table GS-12-3, samples 5 and 6).

A conspicuous, 5 m wide mineralized alteration zone (Table GS-12-3, sample 7) within dacite-rhyolite in the north part of the Bernic Lake Formation crops out at the junction of the Tall Timber Lodge road and PR 314. The felsic hostrock contains massive pyrite-pyrrhotite stringers within a 1.5 m wide zone containing disseminated sulphides. Silicification and pervasive chlorite-hornblende–rich domains are associated with the mineralization, which may represent a former hydrothermal alteration zone. Similar chlorite-hornblende alteration occurs sporadically along the north flank of the Bernic Lake Formation to the east (*see* 'Bernic Lake Formation' section), which may therefore be prospective for base-metal mineralization.

Carbonate-chert iron formation close to the north margin of the Bernic Lake Formation contains a narrow (0.5 m) pyritized zone (Table GS-12-3, sample 8; *see* 'Bernic Lake Formation' section) and may represent a prospective target for base-metal and/or Au exploration. A different mineralized setting occurs at the south margin of the greenstone belt, where felsic volcanic rocks in contact with the Lac du Bonnet granitic batholith to the south are pervasively iron stained due to disseminated pyrite and pyrrhotite in a zone up to 5 m wide (Table GS-12-3, samples 9 and 10; Gilbert, 2007c). In addition, a unit of heterolithic volcanic breccia at the north margin of the Bernic Lake Formation is characterized by extensive iron staining and disseminated pyrite (Table GS-12-3, samples 11, 12 and 13). These rocks are interpreted as a tectonic slice emplaced along the south margin of the Booster Lake Formation.

Acknowledgments

S. Gallagher proved a very capable assistant and contributed substantially to the project, both in the field and at the computer, as well as subsequently in the rock preparation laboratory. He is thanked for his thorough and dependable work. Thanks are also due to the staff at the MGS rock preparation laboratory and the equipment storage facility, who provide ongoing support for all the mapping programs. The author is grateful to B. Lenton, who drafted the accompanying figures and particularly indebted to C. Böhm for his meticulous editing of this paper.

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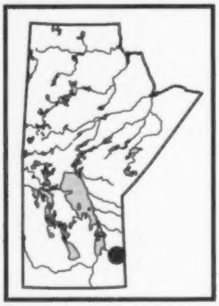
GS-13 Structural geology and kinematic evolution of the Bird River greenstone belt, English River Subprovince, Manitoba (NTS 52L5, 6)

by M. Duguet[1], S. Lin[1], H.P. Gilbert and M.T. Corkery



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Summary

This report synthesizes structural and kinematic data that relate to the tectonic evolution of the Bird River greenstone belt (BRGB). The structures of the BRGB reflect a long-lived transpressive regime during which at least two kinematic events are distinguished. A D_1 event is characterized by north-side-up shearing coeval with some backthrusting. This event is coeval with an episode of metamorphism that produced amphibolite-facies mineral assemblages. A D_2 event corresponds to a reworking of the previous structures. It is characterized by south-side-up shearing with a dextral strike-slip component in the eastern part of the belt. The D_2 event occurred during the emplacement of pegmatitic granite bodies and the Marijane Lake granite, with the latter dated by U-Pb zircon geochronology at 2645.6 ±1.3 Ma (U-Pb on monazite; D. Davis, pers. comm., 2006).

Further investigations in the English River Subprovince in the summer of 2007 have highlighted the kinematic pattern of a major shear zone separating the English River Subprovince (ERSP) from the BRGB. This 3–4 km wide, northwest-trending shear zone on the northern edge of the Maskwa Batholith displays conspicuous dextral shear sense coeval with a magmatic event in the metasedimentary rocks of the ERSP. This dextral event is similar to the dextral shearing that took place east of the BRGB at ca. 2645 Ma (Duguet et al., 2006).

New geochronological data on the Maskwa Batholith give a U-Pb zircon crystallization age of 2830 ±1 Ma (U-Pb on zircon; D. Davis, pers. comm., 2007). This age brings into perspective the role played by the Maskwa granite during the collision between the North Caribou Terrane and the Winnipeg River Subprovince. It suggests that the Maskwa Batholith acted as a small rigid microcontinent during this collision event and, as such, must be considered a distinct subprovince between the ERSP and the BRGB.

Introduction

The Bird River Greenstone Belt (BRGB) is located in southeastern Manitoba, about 150 km northeast of Winnipeg (Figure GS-13-1). It is situated between the English River Subprovince to the north and the Winnipeg River Subprovince to the south. The BRGB is a significant district for ore deposits (e.g. the Tanco rare element pegmatite and the Maskwa [Fe-Ni-Cu-PGE] and Dumbarton [Ni-Cu-Zn-PGE] deposits). The area has been explored for ore deposits since the 1920s. Despite its obvious economic importance, few regional geological maps that include the BRGB have been published (Davies, 1952; Trueman 1980; Cerny et al., 1981). Furthermore, the available maps display numerous inconsistencies and are in need of updating.

A collaborative geological mapping project was initiated in 2005 by the Manitoba Geological Survey and the University of Waterloo, with financial support from the Natural Sciences and Engineering Research Council of Canada (NSERC) and the following mining and exploration companies: Gossan Resources Limited, North American Palladium Ltd., Marathon PGM Corporation, Mustang Minerals Corp. and Tantalum Mining Corporation of Canada Ltd. The objectives of the project are to improve the understanding of the stratigraphic, structural and tectonic framework of the BRGB and to establish the setting of the various mineral deposits that occur within it. This three-year, multidisciplinary project involves targeted bedrock mapping, structural analysis, lithogeochemistry and U-Pb geochronology. The preliminary results of fieldwork undertaken in 2005 and 2006 were published in Duguet et al. (2005) and Duguet et al. (2006).

Field investigations in 2007 were focused on the north flank of the Maskwa Batholith and the adjacent English River Subprovince (ERSP), and in some key areas of the BRGB. The objectives of the 2007 work were to

1) investigate the boundary between the BRGB and the ERSP in order to place the structural pattern of the BRGB into a regional geodynamic setting;
2) complete the mapping of the BRGB; and
3) sample for geochronology and geochemistry, especially in the northern part of the BRGB and the ERSP.

In this report, new data relating to the geology, structure, geochemistry and metamorphism of the northern margin of the Maskwa Batholith and ERSP metasedimentary rocks, as well as geochronological data, are integrated to provide an updated geological and regional structural framework for the BRGB. The objectives are to help establish a revised tectonic history

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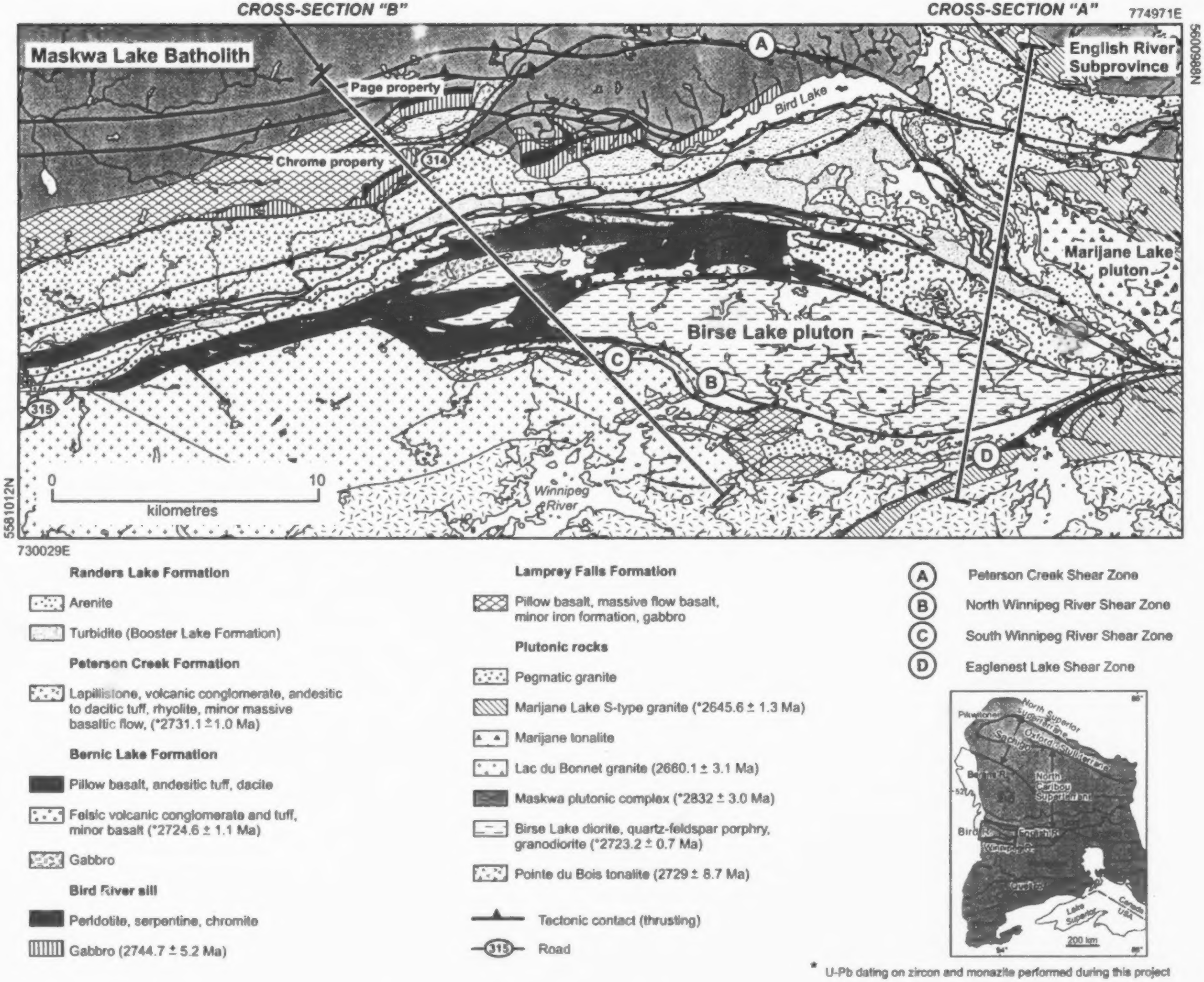
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5581012N
730029E
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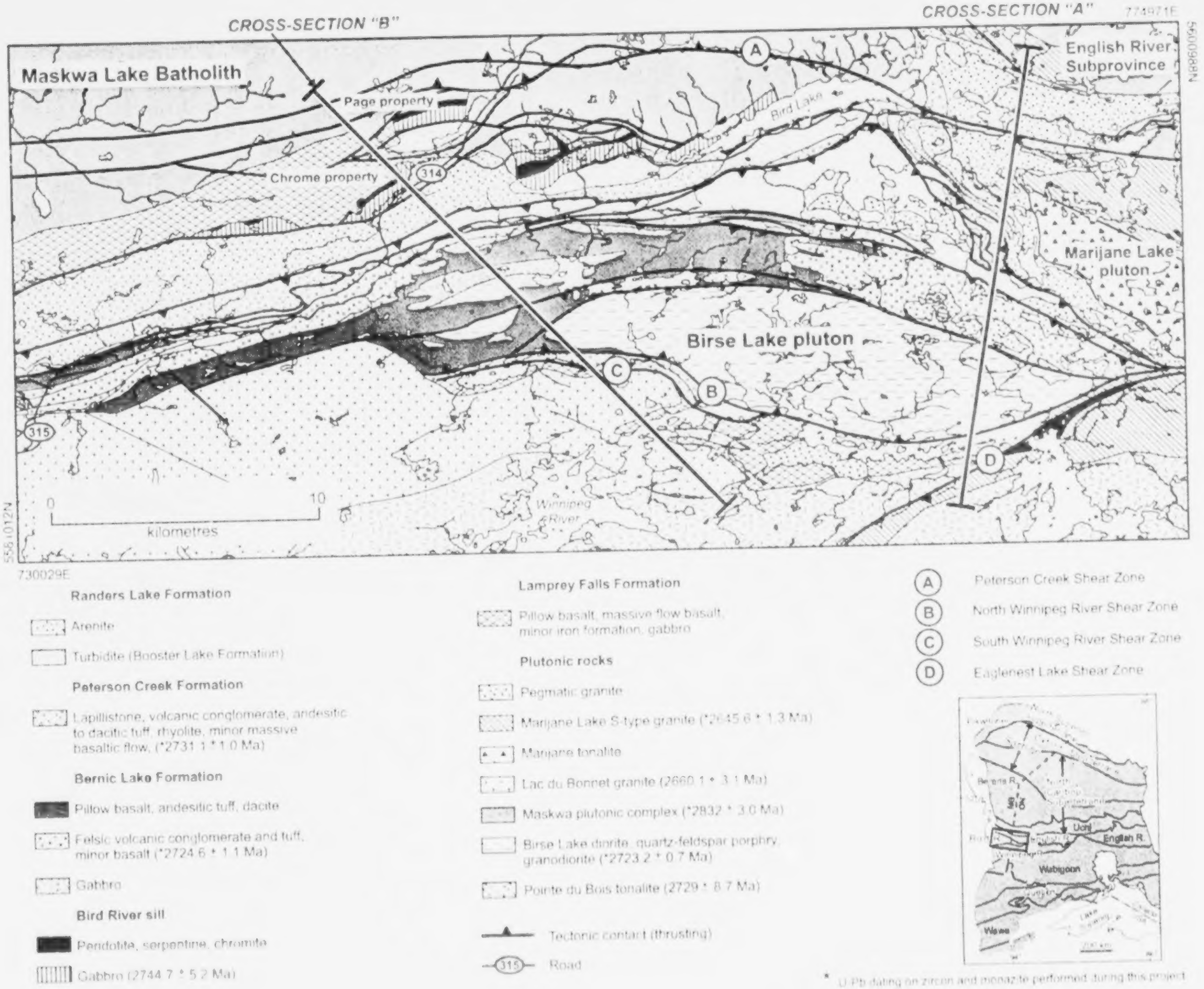
English River Subprovince
Page property
Chrome property
Bird Lake
Marijane Lake pluton
Birse Lake pluton
Winnipeg River
314
315
0
10
kilometres
A
B
C
D
Randers Lake Formation
Arenite
Turbidite (Booster Lake Formation)
Peterson Creek Formation
Lapillistone, volcanic conglomerate, andesitic to dacitic tuff, rhyolite, minor massive basaltic flow, (*2731.1 ± 1.0 Ma)
Bernic Lake Formation
Pillow basalt, andesitic tuff, dacite
Felsic volcanic conglomerate and tuff, minor basalt (*2724.6 ± 1.1 Ma)
Gabbro
Bird River sill
Peridotite, serpentine, chromite
Gabbro (2744.7 ± 5.2 Ma)
Lamprey Falls Formation
Pillow basalt, massive flow basalt, minor iron formation, gabbro
Plutonic rocks
Pegmatic granite
Marijane Lake S-type granite (*2645.6 ± 1.3 Ma)
Marijane tonalite
Lac du Bonnet granite (2660.1 ± 3.1 Ma)
Maskwa plutonic complex (*2832 ± 3.0 Ma)
Birse Lake diorite, quartz-feldspar porphry, granodiorite (*2723.2 ± 0.7 Ma)
Pointe du Bois tonalite (2729 ± 8.7 Ma)
Tectonic contact (thrusting)
Road
A Peterson Creek Shear Zone
B North Winnipeg River Shear Zone
C South Winnipeg River Shear Zone
D Eaglenest Lake Shear Zone
North Superior Superterrane
Oxford-Stull terrane
Sachigo
Berens R.
North Caribou Superterrane
Bird R.
English R.
Winnipeg R.
Lake Superior
Canada
USA
200 km
* U-Pb dating on zircon and monazite performed during this project

Figure GS-13-1: Simplified geological and structural map of the Bird River greenstone belt, southeastern Manitoba.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CROSS-SECTION "A"
774971E
5600988N
Maskwa Lake Batholith
Page property
Chrome property
Bird Lake
English River Subprovince
Marijane Lake pluton
Birse Lake pluton
314
315
A
B
C
D
Winnipeg River
0
10
kilometres
5581012N
730029E
Randers Lake Formation
Arenite
Turbidite (Booster Lake Formation)
Peterson Creek Formation
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Bernic Lake Formation
Pillow basalt, andesitic tuff, dacite
Felsic volcanic conglomerate and tuff, minor basalt (*2724.6 ± 1.1 Ma)
Gabbro
Bird River sill
Peridotite, serpentine, chromite
Gabbro (2744.7 ± 5.2 Ma)
Lamprey Falls Formation
Pillow basalt, massive flow basalt, minor iron formation, gabbro
Plutonic rocks
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Marijane tonalite
Lac du Bonnet granite (2660.1 ± 3.1 Ma)
Maskwa plutonic complex (*2832 ± 3.0 Ma)
Birse Lake diorite, quartz-feldspar porphry, granodiorite (*2723.2 ± 0.7 Ma)
Pointe du Bois tonalite (2729 ± 8.7 Ma)
Tectonic contact (thrusting)
315 Road
A Peterson Creek Shear Zone
B North Winnipeg River Shear Zone
C South Winnipeg River Shear Zone
D Eaglenest Lake Shear Zone
Uchi
English R.
Wabigoon
Wawa
* U-Pb dating on zircon and monazite performed during this project

Figure GS-13-1: Simplified geological and structural map of the Bird River greenstone belt, southeastern Manitoba.

and to provide geological context for mineral deposits in this economically important area.

Stratigraphy

This report briefly describes the stratigraphy of the BRGB. Recent mapping by Gilbert has extensively revised the stratigraphy of the BRGB. Gilbert has defined six main units, which are briefly described below. The reader is referred to Gilbert (2006, GS-12, this volume) for further details.

- The Lamprey Falls Formation, which consists of pillowed basalt with intercalated tuff and iron formation, is in fault contact with the Eaglenest Lake Formation and the Peterson Creek Formation. It is considered to be the oldest unit of the BRGB (Trueman, 1980; Gilbert, 2006). This formation is present on both flanks of the BRGB and is chemically comparable to enriched mid-ocean-ridge basalt (E-MORB), which is typically emplaced in a back-arc setting (Gilbert, 2006, GS-12, this volume). On the south flank of the belt, the northern limit of this unit has been extended north of the Birse Lake Batholith on the basis of chemistry (Gilbert, GS-12, this volume) and is now interpreted to include basalt previously mapped as the Bernic Lake Formation. The two units are separated by an east-trending shear zone, exposed on the north shore of Bernic Lake (Kremer, 2005; Gilbert, GS-12, this volume). On the north flank of the belt, the Lamprey Falls Formation is intruded by an ultramafic–mafic intrusion known as the Bird River Sill. In reality, this sill corresponds to several discontinuous and separate small gabbroic and peridotitic intrusions hosting Cr–platinum group element (PGE) and minor base-metal sulphide mineralization (Mealin, 2006). The sill is dated at 2745 ±5 Ma (U-Pb on zircon, Timmins et al., 1985) and provides a minimum age constraint on the Lamprey Falls Formation. The Birse Lake granodiorite, dated at 2723.2 ±0.7 Ma (U-Pb on zircon, D. Davis, pers. comm., 2007), also intrudes the Lamprey Fall Formation.
- The Eaglenest Lake Formation is composed of volcaniclastic sedimentary rocks and minor mafic lavas. This unit is located on the south flank of the BRGB along the Winnipeg River and crops out only in a limited area. The original stratigraphic position of the Eaglenest Lake Formation is uncertain as it is in fault contact with the Lamprey Falls Formation.
- The Peterson Creek Formation contains rhyolite, andesite and minor basaltic flows, pyroclastic breccia, lapillistone tuff and volcanic sandstone. A large percentage of this formation is composed of sedimentary rocks, including turbidite, calcschist, and chert interlayered with minor felsic volcanic rocks (Gilbert, GS-12, this volume). This subunit is well represented on the north side of the BRGB, where it is in fault contact with the Bird River Sill and the Lamprey Falls Formation. The Peterson Creek Formation falls within the north panel, in the terminology of Gilbert (2006). This formation was previously dated (U-Pb zircon analysis) at 2740 ±4 Ma (Wang, 1993). New dating (U-Pb on zircon) on a rhyolite has provided an age of 2731.1 ±1.0 Ma (D. Davis, pers. comm., 2007). The chemistry shows that the volcanic rocks of the Peterson Creek Formation were emplaced in an arc setting. Spider diagrams on rare earth elements (REE) display calcalkaline affinities (Gilbert, 2006; Duguet et al., 2006).
- The Bernic Lake Formation is composed predominantly of basalt with subordinate andesite, dacite, rhyolite, iron formation and minor volcanic sandstone. All of these rock types have been deformed and metamorphosed up to the middle-amphibolite facies. The formation is widely intruded by granodiorite, diorite and gabbro plutons. The Tanco pegmatite (2640 ±7 Ma by U-Pb on tantalite; Baadsgaard and Cerny, 1993) occurs within one of the gabbroic plutons. As mentioned above, the Bernic Lake Formation is now restricted to the area north of the fault along the north shore of Bernic Lake. The Bernic Lake Formation displays geochemistry akin to arc-tholeiite (Gilbert, 2006), indicating that it is distinct from the Peterson Creek Formation. In the terminology of Gilbert, the Bernic Lake Formation falls within the south panel. New dating on a dacite has given an age of 2724.6 ±1.1 Ma (U-Pb on zircon, D. Davis, pers. comm., 2007).
- The Booster Lake Formation is composed mainly of greywacke-mudstone turbidite. Interbedded conglomerate and iron formation have been observed on the western side of the BRGB within this formation (Cerny et al., 1981). This sequence is strongly deformed and a synclinorial structure has been mapped at Booster Lake in the eastern part of the formation (Gilbert, 2005). This formation has undergone high temperature–low pressure metamorphism coeval with emplacement of the Marijane Lake pluton and the associated pegmatitic granite bodies. On the basis of dating of detrital zircons (U-Pb) by inductively coupled plasma–mass spectrometry (ICP-MS), the maximum age of deposition of this unit can be limited to 2712 ±17 Ma by the age of the youngest detrital zircon (Gilbert, 2006).
- The Flanders Lake Formation is composed of polymictic conglomerate, which includes tonalitic and mafic clasts and metamorphosed lithic meta-arenite. The Flanders Lake Formation is intruded by the Marijane Lake pluton and is in fault contact with the Peterson Creek, Booster Lake and Bernic Lake formations. On the basis of the dating of detrital zircons (U-Pb) by ICP-MS, this unit is considered as

the youngest in the BRGB (<2697 ±18 Ma; Gilbert, 2006).

Deformation structure and kinematics of the Bird River greenstone belt, regional framework

For detailed description of structure and shear zones, the reader is referred to Duguet et al. (2005) and Duguet et al. (2006). The following sections attempt to present a coherent tectonic model for the BRGB and the adjacent ERSP based on all data collected during the summers of 2005, 2006 and 2007.

Tectonic evolution of the Bird River greenstone belt

The Bird River greenstone belt (BRGB) was first affected by apparent vertical movements with a minor strike-slip component. Along the north flank of the belt, the east-trending Peterson Creek Shear Zone (PCSZ) deforms the Maskwa granite with a north-side-up offset. The central part of the belt, consisting of supracrustal formations, was affected by a south-side-up shearing (Figure GS-13-2). This event led to tectonic thrusting of the Bernic Lake Formation from the south (present co-ordinates) over the Booster Lake and Peterson Creek formations to the north and the Flanders Lake Formation to the east. In the northern part of the belt, this event is coeval with an amphibolite facies metamorphism that reached peak conditions (550°C, 5kbar) after a pressure increase. This structural framework can be interpreted as an initial low-angle thrusting followed by steepening of all the formations. This interpretation is supported by new geochronological data, which indicate that the Booster Lake Formation is slightly older than the Flanders Lake Formation (Gilbert, 2006). The actual position of the Booster Lake Formation upon the Flanders Lake Formation can only be explained by overthrusting of the former upon the later.

The Birse Lake granite intrudes the Lamprey Falls Formation (Figure GS-13-1), with their contact modified to the south by the North Winnipeg River Shear Zone (NWRSZ). The North Winnipeg River Shear Zone, where it marks the contact between the two units, shows a dextral and north-side-up shear sense. Southward, the Lamprey Falls Formation is separated from the Winnipeg River Subprovince by a later northeast-trending shear zone with a sinistral and south-side-up shear sense. The sinistral south-side-up tectonic event in the northwestern part of the belt is characterized by northwest-trending upright folds in the east and a northeast-trending, south-side-up shear zone in the west. In the west, the deformation took place under metamorphic conditions that produced greenschist-facies mineral assemblages, retrogressing the previous amphibolite-facies assemblages. In the east, due to late magmatism, the formations experienced high temperature–low pressure metamorphism that produced amphibolite-facies mineral assemblages. The Marijane Lake granite, which has been dated at 2645.6 ±1.3 Ma (U-Pb on monazite; D. Davis, pers. comm., 2006), is coeval with this event.

Structural and kinematic relationships of the Bird River greenstone belt (BRGB) and the English River Subprovince (ERSP)

During the summer of 2007, a survey was undertaken near the northern margin of the Maskwa Batholith in the ERSP. The objective was to characterize the kinematic evolution of the structural boundary between the ERSP and the BRGB.

Deformation and structures in the English River Subprovince

On aerial photographs of the ERSP, a strong, 3–4 km wide, northwest-trending lineament, which is present in the metasedimentary rocks, traces to the southeast where the Maskwa Batholith pinches out and the Flanders Formation of the BRGB and metasedimentary rocks of the ERSP are directly in contact (Figure GS-13-1). The metasedimentary rocks display a northwest-trending foliation that dips steeply to the south. This foliation locally exhibits a northwest-plunging stretching lineation (Figure GS-13-3). The metasedimentary rocks are extensively intruded by white, leucogranitic and pegmatitic dikes emplaced parallel to the regional foliation. The dikes are 2–50 cm wide and regularly spaced. In some zones, the sedimentary rocks are completely replaced by the granite. A marginally younger, pinkish pegmatitic phase of granite is also present and displays strong intermixing with the previous phase, such that it is sometimes difficult to distinguish between them. The pink phase is very similar to the S-type Marijane Lake granite, dated at 2645.6 ±1.3 Ma (U-Pb on monazite, D. Davis, pers. comm., 2006). These dikes display asymmetric boudinage coeval with a dextral shearing (Figure GS-13-4). The dextral shearing occurs during dike emplacement, as the magmatic texture is still preserved and the deformation takes place only on the margins of the dikes. Some dikes display clear plastic deformation at the solidus stage (Figure GS-13-5), which means that the dextral shearing continued after crystallization and cooling of this melt.

The age of the first generation of white granite is unknown. Even though, the pinkish granite seems a bit later, it displays the same structural relationships (especially during the dextral kinematic deformation) as the white granite. This suggests that the two granites may have been emplaced closely in time, ca. 2645 Ma.

Deformation and structures on the northern margin of the Maskwa Batholith

On its northern margin, the Maskwa Batholith is a tonalite that is intruded by numerous mafic dikes. Most of the mafic dikes are northeast-trending, but some display a northwest trend. Both the mafic dikes and the tonalite

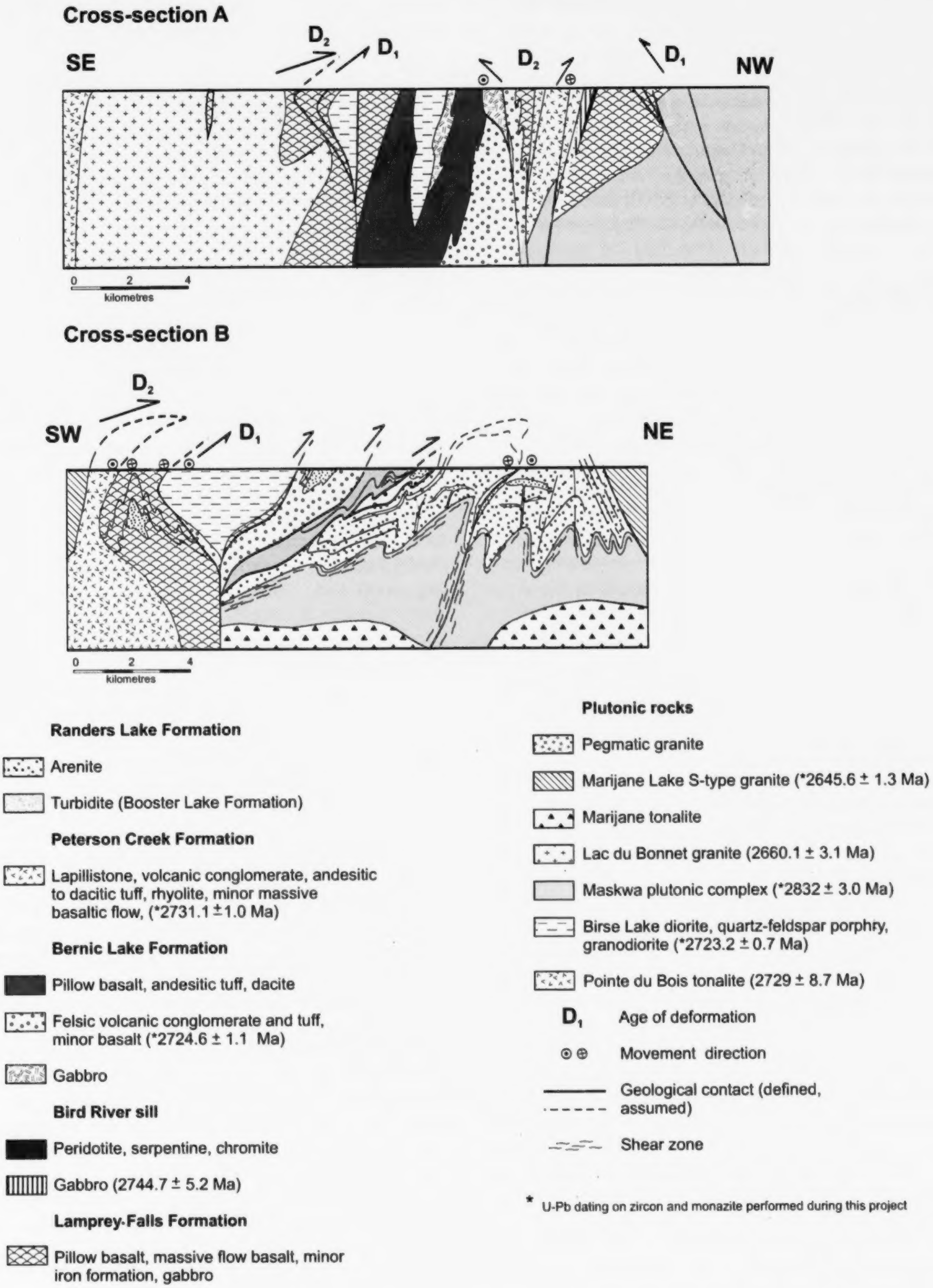
Cross-section A
SE
D2
D1
D2
D1
NW
0 2 4
kilometres
Cross-section B
D2
SW
D1
NE
0 2 4
kilometres
Randers Lake Formation
Arenite
Turbidite (Booster Lake Formation)
Peterson Creek Formation
Lapillistone, volcanic conglomerate, andesitic to dacitic tuff, rhyolite, minor massive basaltic flow, (*2731.1 ±1.0 Ma)
Bernic Lake Formation
Pillow basalt, andesitic tuff, dacite
Felsic volcanic conglomerate and tuff, minor basalt (*2724.6 ± 1.1 Ma)
Gabbro
Bird River sill
Peridotite, serpentine, chromite
Gabbro (2744.7 ± 5.2 Ma)
Lamprey Falls Formation
Pillow basalt, massive flow basalt, minor iron formation, gabbro
Plutonic rocks
Pegmatic granite
Marijane Lake S-type granite (*2645.6 ± 1.3 Ma)
Marijane tonalite
Lac du Bonnet granite (2660.1 ± 3.1 Ma)
Maskwa plutonic complex (*2832 ± 3.0 Ma)
Birse Lake diorite, quartz-feldspar porphry, granodiorite (*2723.2 ± 0.7 Ma)
Pointe du Bois tonalite (2729 ± 8.7 Ma)
D1 Age of deformation
⊙ ⊕ Movement direction
Geological contact (defined, assumed)
Shear zone
* U-Pb dating on zircon and monazite performed during this project

Figure GS-13-2: *Cross-sections of the Bird River greenstone belt, southeastern Manitoba. See Figure GS-13-1) for locations of sections.*

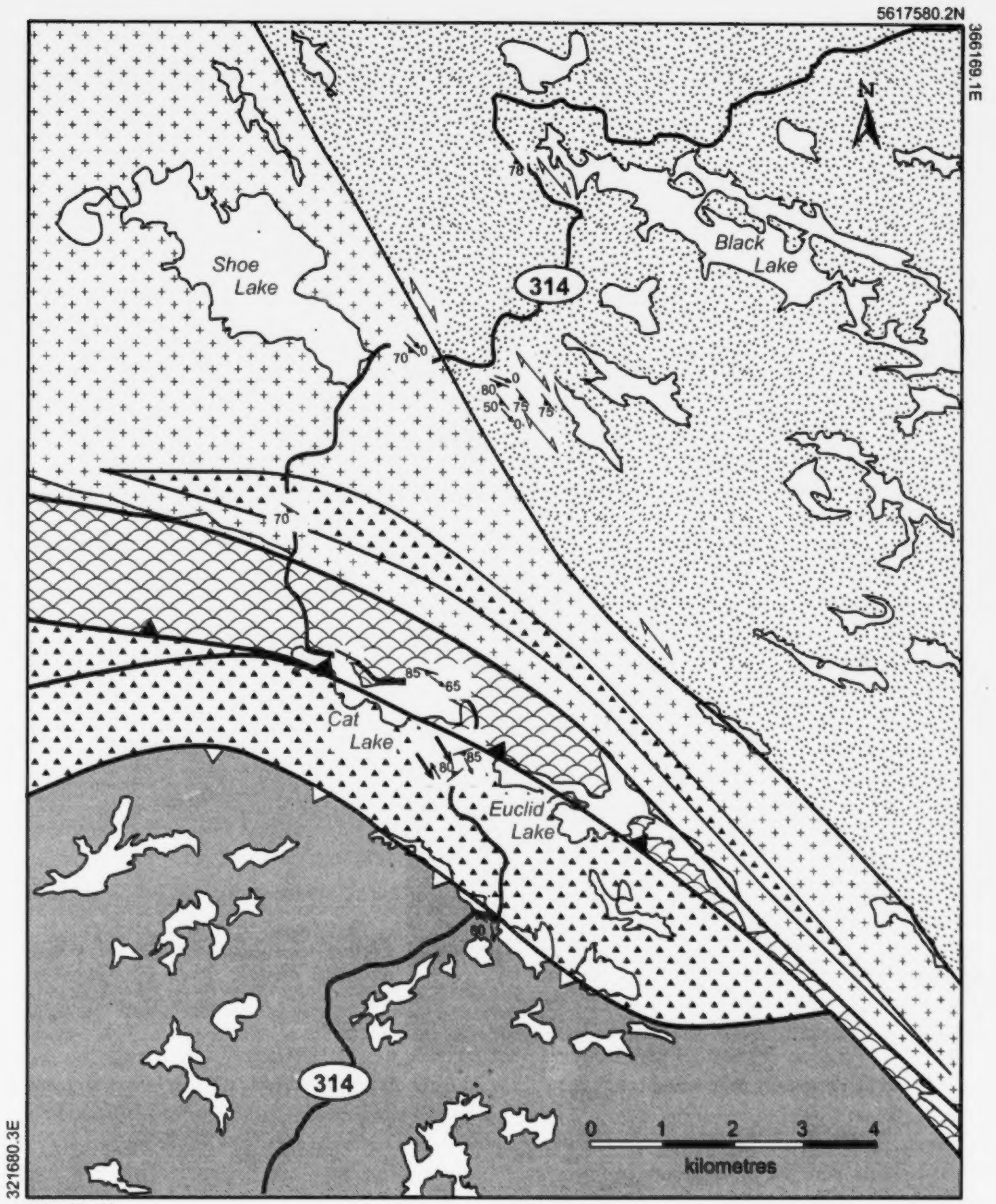
5617580.2N
366169.1E
N
Shoe Lake
Black Lake
Cat Lake
Euclid Lake
314
314
78
70
70
80
50
75
75
0
0
70
85
65
85
80
80
0
1
2
3
4
kilometres
321680.3E
5602156.1N
Late granite
Metasediment
Basalt, gabbro, metasediment
Tonalite
Maskwa plutonic complex (*2832 ± 3.0 Ma)
D1 tectonic contact (thrusting)
D1 direction of kinematic movement (vertical movement)
D2 strike-slip shearing
D2 thrusting
* U/Pb dating on zircon and monazite performed during this project

***Figure GS-13-3:** Simplified structural map of the Maskwa Batholith–English River Subprovince area.*

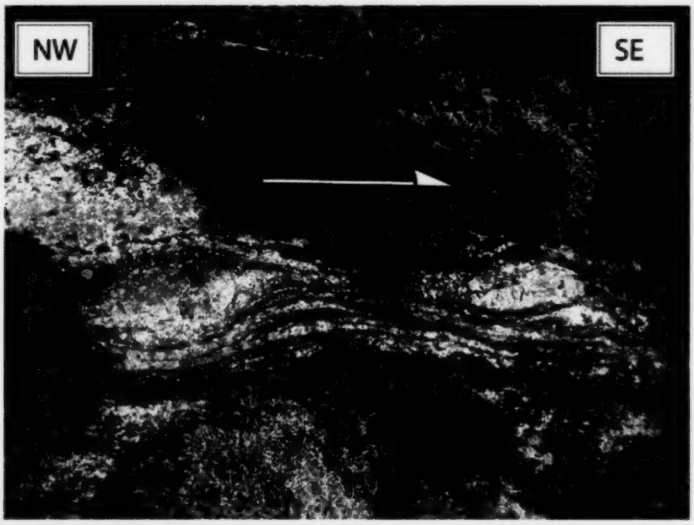

Figure GS-13-4: Asymmetric boudinage of granitic dikes, giving a dextral sense of shear in metasedimentary rocks of the English River Subprovince. Pen for scale.

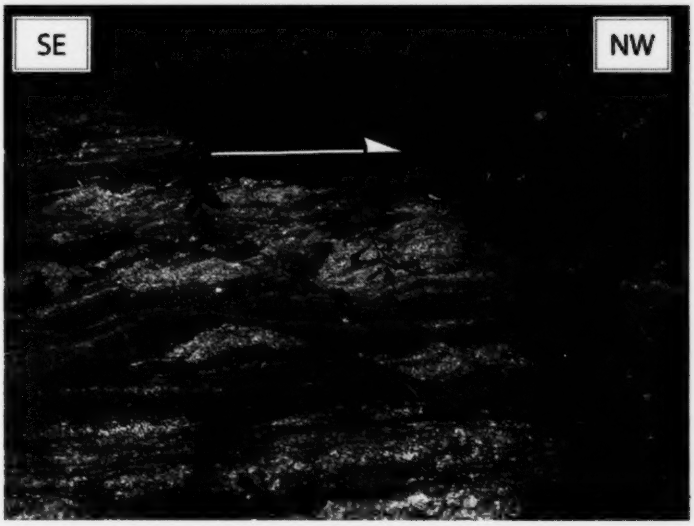

Figure GS-13-5: Late dextral shear bands affecting granitic dikes in metasedimentary rocks of the English River Subprovince. Pen for scale.

are crosscut by late, pink pegmatitic dikes and late S-type granite.

Near the contact with metasedimentary rocks of the ERSP, both the tonalite and the mafic dikes display a strong non-coaxial deformation. The foliation has a northwest trend, dips steeply to the south and exhibits a steeply plunging stretching and mineral lineation. Fabric observed in hand-sample sections cut parallel to the lineation and perpendicular to the foliation display shear criteria (shear bands and asymmetric strain shadow around porphyroclasts), giving a north-side-up sense of shear (Figure GS-13-3). A similar shear sense was found to the southeast in a migmatite (Figure GS-13-4) that crops out inside the sedimentary unit of the ERSP northeast of Tulabi Lake and north of Davidson Lake. The relationships between the sedimentary rocks and migmatite are not clear, as the sedimentary rocks display a horizontal composite stretching and mineral lineation associated with dextral shear. It is difficult to determine if the migmatite corresponds to a tectonic slice or if it is derived by *in situ* melting of the metasedimentary rocks. Because the sedimentary rocks surrounding the migmatite don't display any partial melting, a tectonic emplacement of the migmatite seems more likely. Compared to the PCSZ, the authors interpret the north-side-up shearing in the migmatite to be earlier than the dextral shearing in the sedimentary rocks. The rarity of the north-side-up shearing could be interpreted to mean that this event is older. A lack of clear overprinting relationships, however, leaves the question unresolved.

To the south along Provincial Road 314, another shear zone affects the tonalite and a pink leucogranite that display a strong non-coaxial deformation. The foliation strikes northwest and dips moderately (50°) to the south (Figure GS-13-3). This foliation bears a steeply plunging stretching lineation. In hand-sample sections cut parallel to the lineation and perpendicular to the foliation, shear criteria (shear bands and asymmetric strain shadows around porphyroclasts) give a south-side-up sense of shear (Figures GS-13-6, -7). As this leucogranite seems to be petrographically similar to the Marijane Lake granite, the authors assume that this south-side-up event is a later deformation event coeval with the ca. 2645 Ma emplacement of the Marijane Lake granite.

Geodynamic significance of the Maskwa Batholith

The Maskwa Batholith played a significant role in the tectonic history of both the BRGB and the ERSP because of its size and position between them. As described above, the northern margin of the Maskwa Batholith is occupied by a large-scale, dextral shear zone predominantly within the metasedimentary rocks of the ERSP. Only the northern margin of the Maskwa Batholith is affected by this deformation. The southern margin of the Maskwa Batholith is deformed as well. In contrast to the northern margin, defining a clear structural limit between the Maskwa Batholith and the supracrustal rocks of the BRGB is difficult. Indeed, the first order structures, such as the PCSZ, crosscut all the formations (Maskwa Batholith, Lamprey Falls Formation and Peterson Creek Formation). This feature is quite unusual in a greenstone belt. It is obvious that the Maskwa Batholith underwent a heterogeneous deformation, with shear zones delineating broad areas free of deformation in which the magmatic texture is still preserved. Three different ages have been reported for the Maskwa Batholith (2725.1 ±5.5 Ma, 2782 ±11 Ma, 2844 ±12 Ma from U-Pb on zircon; Wang, 1993). The first age is more or less coeval with those encountered in the BRGB supracrustal rocks, but the other two are significantly older. The Maskwa Batholith is clearly a polyphase pluton, composed of several generations of melt. The proportions of the different generations and their respective importance in the evolution of the BRGB

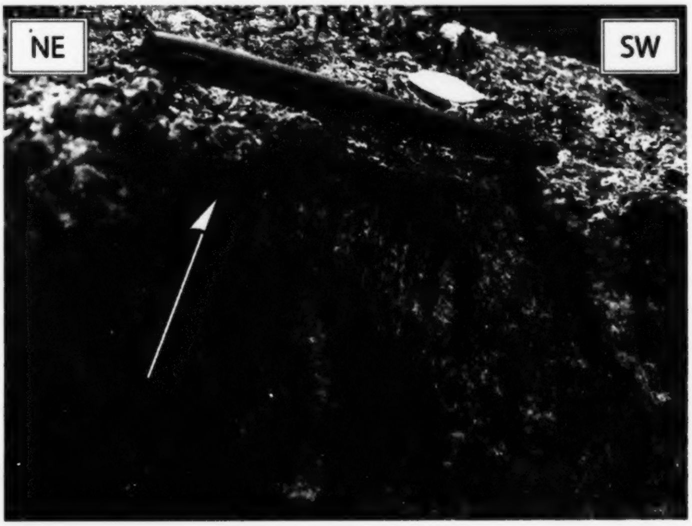

***Figure GS-13-6:** Asymmetric strain shadows around a K-feldspar porphyroclast, giving a north-side-up sense of shearing in migmatite of the English River Subprovince, northeast of Tulabi Lake.*

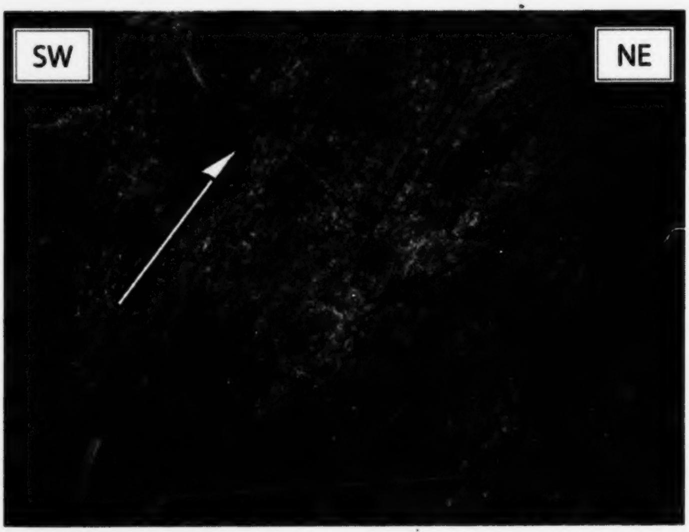

***Figure GS-13-7:** Shear bands, giving a south-side-up sense of shearing in the Maskwa Batholith and late pink granite. Arrow approximately 10 cm long.*

shear criteria (shear bands and asymmetric strain shadows around porphyroclasts) give a south-side-up sense of shear (Figures GS-13-6, -7). As this leucogranite seems to be petrographically similar to the Marijane Lake granite, the authors assume that this south-side-up event is a later deformation event coeval with the ca. 2645 Ma emplacement of the Marijane Lake granite.

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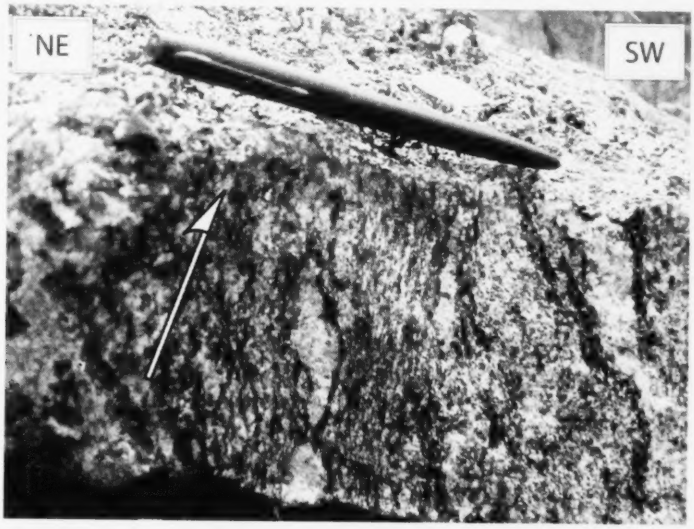

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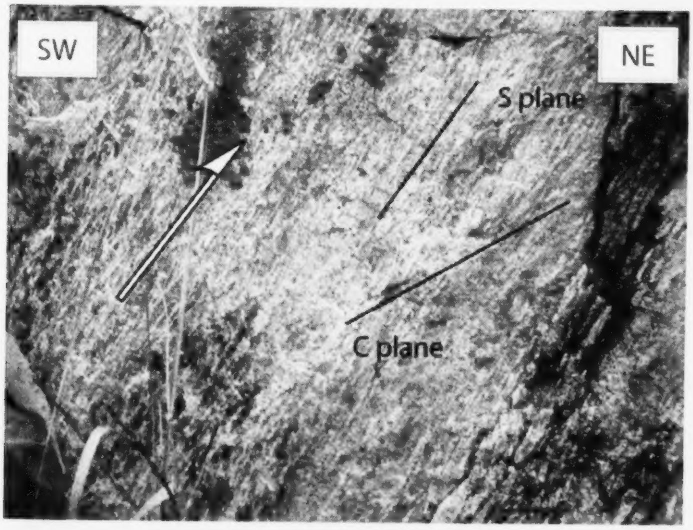

Figure GS-13-7: *Shear bands, giving a south-side-up sense of shearing in the Maskwa Batholith and late pink granite. Arrow approximately 10 cm long.*

remain unknown. For example, is the Maskwa Batholith an older terrane or a younger granite with volumetrically minor older material?

In order to decide between the hypotheses of a young granite coeval with the supracrustal rocks or an older terrane that may form a basement to the adjacent rocks, new geochemical and geochronological data were needed. During the summer of 2006, a sample was collected from the dominant phase of the Maskwa Batholith. This sample was processed and gave an age of 2832 ±3 Ma (U-Pb on zircon; D. Davis, pers. comm., 2007), which is significantly older than any other ages in the BRGB and ERSP. In addition, geochemistry of a prominent set of dikes emplaced into southern margin of the Maskwa Batholith, has produced REE profiles identical to those for basalt of the Lamprey Falls Formation (Figure GS-13-8). One interpretation of these dikes is that they are synvolcanic feeders to the Lamprey Falls Formation (Peck et al., 1999). A corollary of this interpretation is that the volcanic rocks of the Lamprey Falls Formation were likely to have been deposited, at least in part, upon the Maskwa Batholith during back-arc spreading and creation of oceanic crust.

The new data provided by the geochemistry and the geochronology lead to the interpretation of the Maskwa Batholith as an older microcontinent split from a continental margin during back-arc spreading (Lamprey Falls Formation). After this first event, the Maskwa Batholith acted as a small rigid block during the collision between the BRGB and the ERSP. The Maskwa Batholith must therefore be considered a distinct subprovince between the ERSP and the BRGB.

Economic considerations

The Bird River greenstone belt has been extensively explored for ore deposits since 1920, when (Ni-Cu) sulphide deposits were discovered in the Cat Creek–Maskwa River area (McCann, 1921). At present, economic interest is focused on mineralization allied to three known ore deposits:

- Tanco rare-element pegmatite emplaced ca. 2640 Ma. Mapping has been interpreted to indicate that the Tanco pegmatite was emplaced in a still-active tectonic context (Kremer and Lin, 2006)

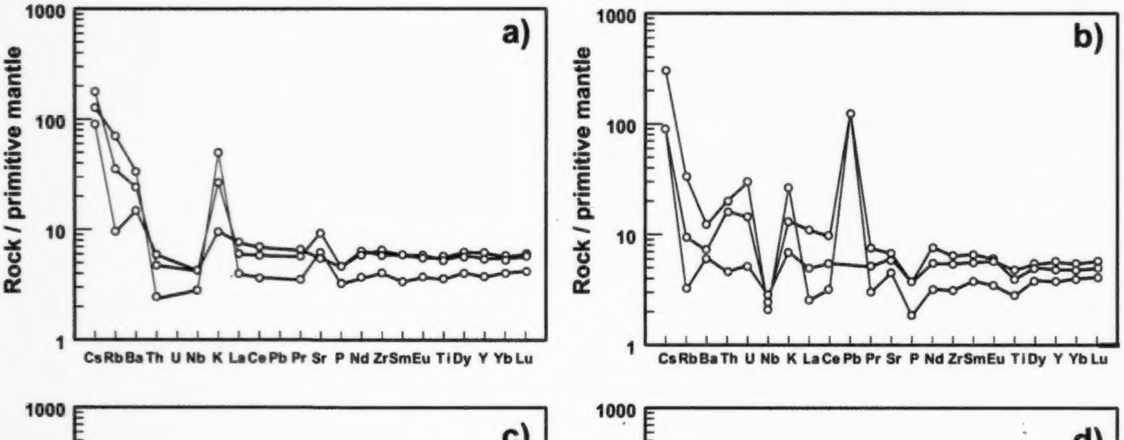

Figure GS-13-8: *Geochemical discrimination diagrams for samples of mafic dikes intruded through the Maskwa Batholith:* ***a)*** *primitive mantle–normalized rare earth element diagram for samples of mafic dikes on the southern margin of the Maskwa Batholith;* ***b)*** *primitive mantle–normalized rare earth element diagram for samples of mafic dikes on the northern margin of the Maskwa Batholith;* ***c)*** *primitive mantle–normalized (Sun and McDonough, 1989) extended-element diagram for samples of basalt from the Lamprey Fall Formation for comparison;* ***d)*** *primitive mantle–normalized (Sun and McDonough, 1989) extended-element diagram for samples of basalt from the Mayville Formation for comparison.*

- Maskwa Fe-Ni-Cu-PGE deposit
- Dumbarton Ni-Cu-Zn-PGE deposit

The Tanco mine at Bernic Lake has produced Ta, Cs and Li since 1969. The Maskwa and Dumbarton deposits were mined from 1974 to 1976 and from 1969 to 1973, respectively. Renewed production at Maskwa is planned due to the recent discovery of additional ore reserves (Mustang Minerals Corp., 2005). In the area north of Bernic Lake, Ni-Cu-PGE mineralization is spatially associated with the mafic–ultramafic Bird River Sill. At the present time, the Bird River greenstone belt is being extensively explored by Tanco for rare element-bearing pegmatite deposits, and by Gossan Resources Limited, Marathon PGM Corporation and Mustang Minerals Corp. for Ni-Cu-Zn-PGE mineralization.

The new geochronological data on the Maskwa Batholith support a new interpretation of its geodynamic significance. The age of 2830 Ma demonstrates that the Maskwa Batholith must now be considered an independent microcontinent that split off during a back-arc spreading event. It is worth noting that all Ni-Cu-Zn-PGE occurrences in mafic–ultramafic bodies are associated with this event and are found on the both sides of the Maskwa Batholith, in the Bird River Sill and Maskwa-Dumbarton mine to the south, and in the Mayville Formation to the north. One implication is that a rigid microcontinent, such as the Maskwa Batholith, may have played a significant role in the preservation of these deposits. In comparison, mafic and ultramafic rocks formed as remnants of oceanic crust, are more sensitive to destruction in subduction environments. The presence of low-density microcontinents intruded by mafic and ultramafic rocks can permit the preservation on their margins of some relics of oceanic crust. These microcratons, and especially their boundaries, should constitute new targets for future Ni-Cu-Zn-PGE exploration.

Acknowledgments

The Manitoba Geological Survey, the University of Waterloo, Gossan Resources Limited, Marathon PGM Corporation and North American Palladium Ltd., Mustang Minerals Corp. and Tantalum Mining Corporation of Canada Ltd. have generously supplied funding for this project. P. Kremer and C. Mealin are gratefully acknowledged for sharing their ideas on the Bird River belt. Field assistant Ellen Reid provided voluntary assistance in the field throughout the summer. The manuscript was considerably improved by the thoughtful comments of A. Bailes. who also generously made available unpublished geochemical analyses of the Lamprey Falls and Mayville formations.

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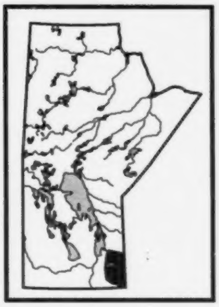
GS-14

Using tree-ring data to understand summer drought in a key watershed for Manitoba Hydro

by S. St. George[1] and D.M. Meko[2]

St. George, S. and Meko, D.M. 2007: Using tree-ring data to understand summer drought in a key watershed for Manitoba Hydro; *in* Report of Activities 2007, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 155–160.



Summary

The Winnipeg River basin drains parts of northwestern Ontario, northern Minnesota and southeastern Manitoba, and is a key area for hydroelectric power production in Manitoba. This study uses a network of 54 tree-ring records to estimate changes in summer climate within the Winnipeg River basin, Canada since 1783 AD. Most records were developed from *Pinus resinosa* and *P. strobus*, with a limited number of collections made from *Thuja occidentalis*, *Picea glauca* and *Pinus banksiana*. Tree growth is significantly, but weakly, correlated with both temperature and precipitation during summer. High and low growth across the region is associated with cool/wet and warm/dry summers respectively; this relationship is supported by comparisons with archival records from early 19th century fur-trading posts. The tree-ring record indicates that summer droughts were more persistent in the 19th and late 18th century, but there is no evidence that drought was more extreme prior to the onset of direct monitoring.

Introduction

The Winnipeg River in south-central Canada is the largest single source of water used to generate hydroelectricity in the Canadian Prairies. Water managers have expressed an interest in understanding how the hydrology of this and other watersheds in the region has behaved during the last millennium, and have supported a number of independent research projects using several types of environmental proxies (Moos et al., 2005; Beriault and Sauchyn, 2006). This study uses a multispecies network of trees at sites within the Winnipeg River region to examine the nature of the environmental signals recorded in regional tree-ring data. A combination of empirical orthogonal function and response function analyses, and forward modelling are used to determine 1) if trees growing in this cool, moist environment retain a climate signal within their annual growth increment; 2) what factors might be responsible for creating that signal; and 3) if this information can be used to make inferences about climatic conditions prior to the onset of instrumental monitoring. This project is part of a larger study investigating the frequency and causes of hydrological drought in the Winnipeg River basin (St. George, 2007).

Study area

The Winnipeg River region is immediately west of Lake Superior and occupies the western edge of the Superior Province of the Canadian Shield. The region can be described generally as heavily forested, with little local relief, frequent bedrock outcrops and many large lakes. Where they are present, surficial deposits are mainly sandy tills derived from the surrounding Shield (Dredge and Cowan, 1989). Glaciolacustrine clay deposited in glacial Lake Agassiz is also present in the westernmost sector of the region, including the Lake of the Woods area. The Winnipeg River is a bedrock-channel river that begins at the northern end of Lake of the Woods and terminates in the south basin of Lake Winnipeg. The river is the single largest source of water to Lake Winnipeg and influences the production of over 4600 MW of hydroelectricity (St. George, 2007).

Tree-ring data

Tree-ring samples were collected at 24 sites in the Winnipeg River region between July and August in 2004 and 2005. At two sites (Moose Lake and Turtle Lake), samples were taken from both red and white pine, bringing the total number of new tree-ring collections to 26. Sampling concentrated on the three longest-lived tree species in this area: eastern white pine (*Pinus strobus*), red pine (*Pinus resinosa*) and eastern white cedar (*Thuga occidentalis)*. Stand-age maps provided by Abitibi Consolidated Inc. and the Ontario Ministry of Natural Resources were used as a guide to identify stands of older trees as targets for collection. This collection was supplemented by ringwidth data obtained from the International Tree-Ring Data Bank (National Oceanic and Atmospheric Administration, 2007) for sites located within the greater Winnipeg River region (47–52°N, 90–96°W). Data from an additional 15 sites was provided by Martin Girardin (pers. comm., 2006).

The combined network is made up of 54 ringwidth records from 44 sites in the Winnipeg River area (Figure GS-14-1). The dataset includes measurements of nearly 2000 radii from almost 1000 trees. Most collections are developed from red pine (24 records) and white pine (21), with a limited number made from eastern white cedar (3), jack pine (*Pinus banksiana*, 3), white spruce

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[2] Laboratory of Tree-Ring Research, University of Arizona, Tucson, Arizona 85721

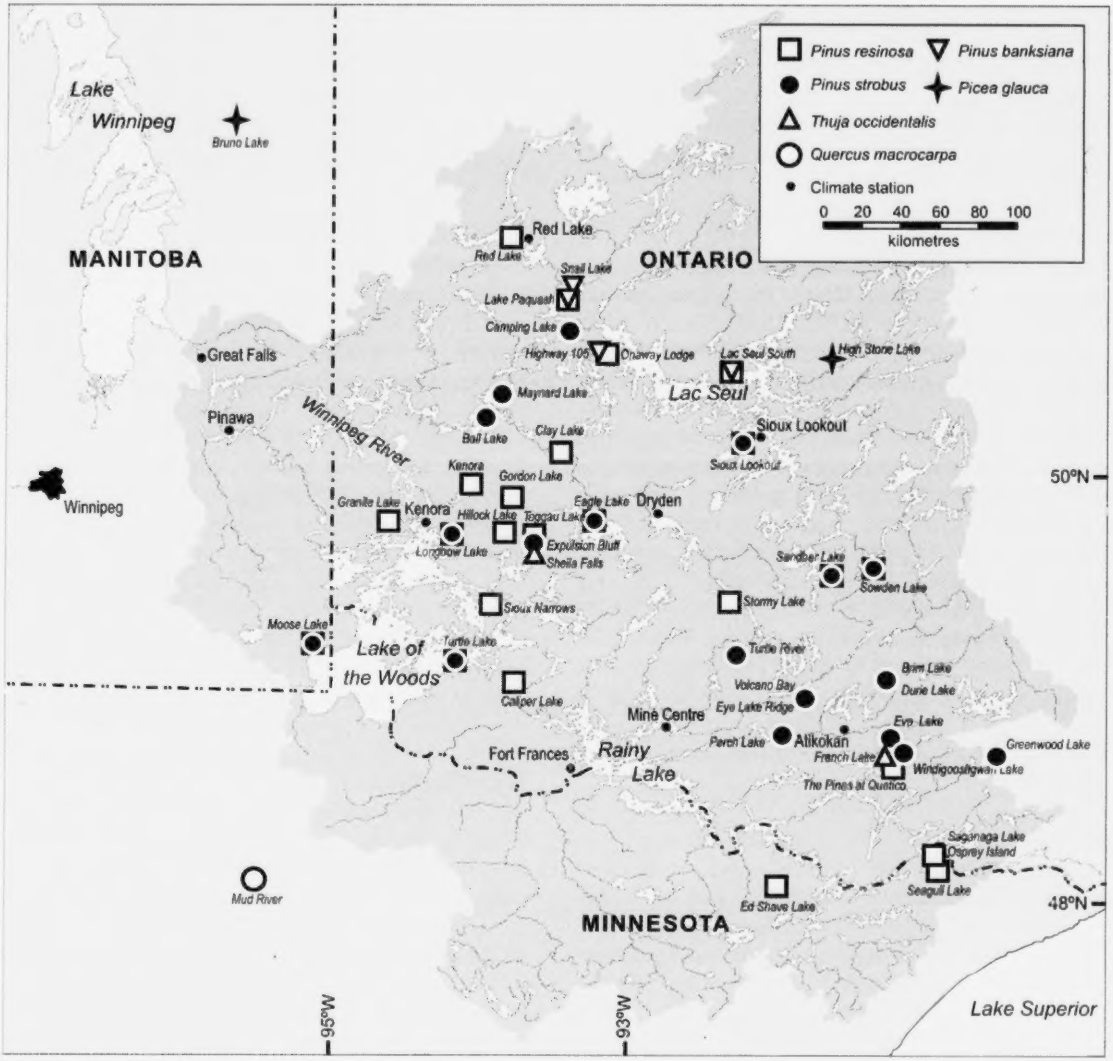

Pinus resinosa
Pinus banksiana
Pinus strobus
Picea glauca
Thuja occidentalis
Quercus macrocarpa
Climate station
0 20 40 60 80 100
kilometres
Lake Winnipeg
Bruno Lake
MANITOBA
ONTARIO
Red Lake
Red Lake
Snail Lake
Lake Paquash
Camping Lake
Highway 105
Onaway Lodge
Lac Seul South
High Stone Lake
Lac Seul
Great Falls
Pinawa
Winnipeg River
Maynard Lake
Ball Lake
Clay Lake
Sioux Lookout
Sioux Lookout
Kenora
Gordon Lake
50°N
Winnipeg
Granite Lake
Kenora
Hillock Lake
Teggau Lake
Eagle Lake
Dryden
Longbow Lake
Expulsion Bluff
Sheila Falls
Sandbar Lake
Sowden Lake
Sioux Narrows
Stormy Lake
Moose Lake
Turtle Lake
Lake of the Woods
Turtle River
Brim Lake
Volcano Bay
Durie Lake
Caliper Lake
Eye Lake Ridge
Mine Centre
Eye Lake
Perch Lake
Atikokan
Greenwood Lake
French Lake
Windigoostigwan Lake
Fort Frances
Rainy Lake
The Pines at Quetico
Saganaga Lake
Osprey Island
Seagull Lake
Mud River
Ed Shave Lake
MINNESOTA
48°N
95°W
93°W
Lake Superior

Figure GS-14-1: *Tree-ring sites and climate stations in the Winnipeg River region, Manitoba. Base map provided by the Lake of the Woods Control Board.*

(*Picea glauca*, 2) and bur oak (*Quercus macrocarpa*, 1). The majority of sites are located in the central part of the watershed in northwestern Ontario. There is only a single site in southeastern Manitoba and none in northwestern Minnesota, largely because of the increasing prevalence of grassland ecosystems in the western and southern part of the region.

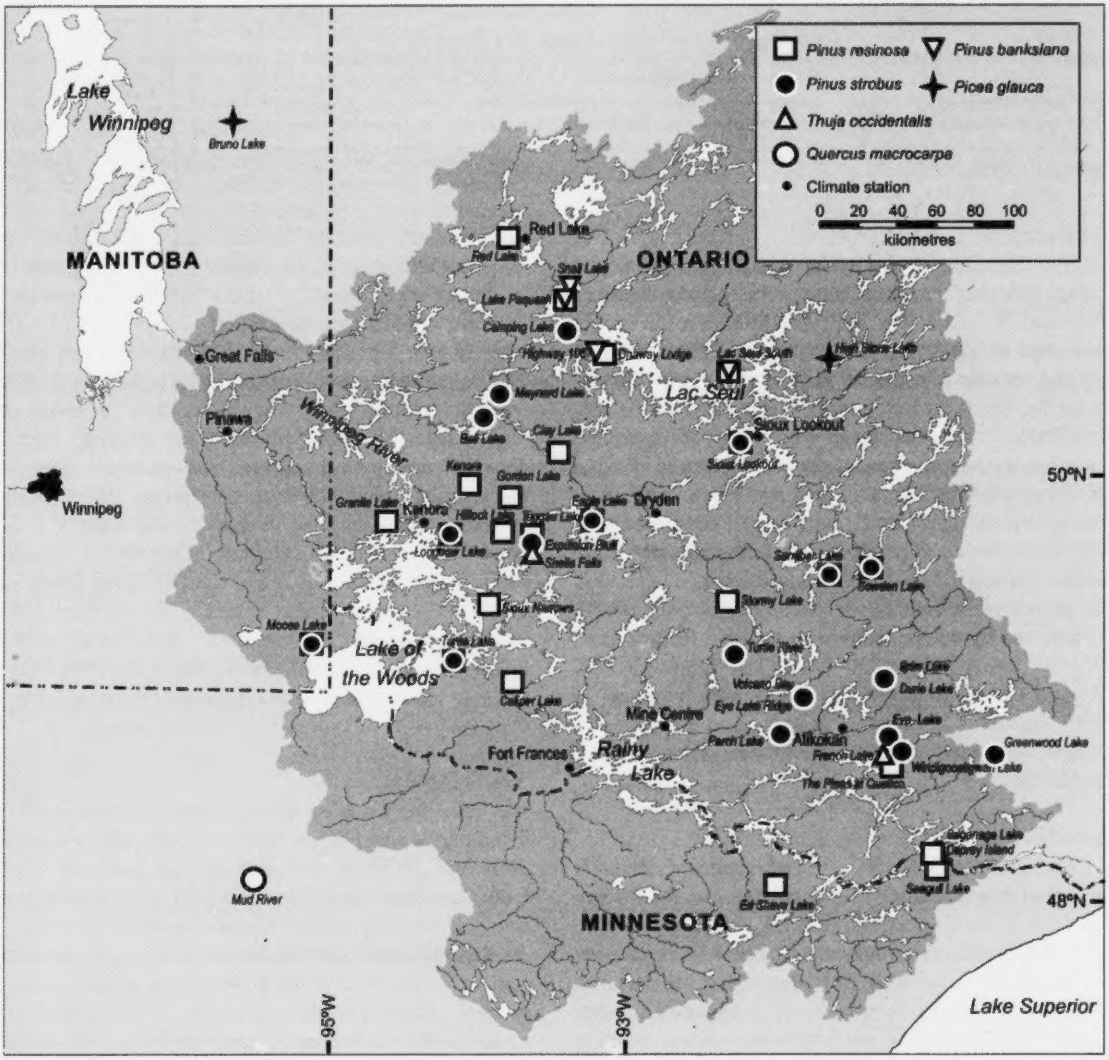
Methods

Samples were prepared, cross-dated and measured following standard dendrochronological techniques (Stokes and Smiley, 1968). Empirical orthogonal function (EOF) analysis (North et al., 1982; Peixoto and Oort, 1992) was used to identify the dominant modes of variability present in the ringwidth network. The EOF analysis was repeated several times to determine the sensitivity of the final results to the choice of 1) detrending method, 2) the interval used for analysis (and associated spatial coverage of the tree-ring network), and 3) the application of the EOF technique. Potential relationships between annual tree growth and climate variables were assessed using correlation and response functions (Fritts, 1976) generated using DENDROCLIM2002 (Biondi and Waikul, 2004). In this program, bootstrapped confidence intervals are determined by shuffling the matrix of climate data 1000 times and calculating the 95th percentile range of the coefficients obtained from the randomized data.

Results

Chronology characteristics

Most ringwidth chronologies in the Winnipeg River


Pinus resinosa
Pinus banksiana
Pinus strobus
Picea glauca
Thuja occidentalis
Quercus macrocarpa
Climate station
0 20 40 60 80 100
kilometres
Lake Winnipeg
Bruno Lake
MANITOBA
ONTARIO
MINNESOTA
Red Lake
Red Lake
Snail Lake
Lake Paquash
Camping Lake
Highway 105
Ourway Lodge
Lac Seul South
High Stone Lake
Lac Seul
Sioux Lookout
Sioux Lookout
Maynard Lake
Bell Lake
Clay Lake
Great Falls
Pinawa
Winnipeg River
Winnipeg
Kenora
Gordon Lake
Granite Lake
Kenora
Hillock Lake
Eagle Lake
Dryden
Loonbear Lake
Expulsion Bluff
Sheila Falls
Sandbar Lake
Sowden Lake
Sioux Narrows
Stormy Lake
Moose Lake
Turtle Lake
Lake of the Woods
Caliper Lake
Turtle River
Volcano Bay
Eye Lake Ridge
Dune Lake
Mine Centre
Perch Lake
Atikokan
Fort Frances
Rainy Lake
French Lake
Greenwood Lake
The Pines at Quetico
Saganaga Lake
Osprey Island
Seagull Lake
Ed Shave Lake
Mud River
50°N
48°N
95°W
93°W
Lake Superior

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(*Picea glauca*, 2) and bur oak (*Quercus macrocarpa*, 1). The majority of sites are located in the central part of the watershed in northwestern Ontario. There is only a single site in southeastern Manitoba and none in northwestern Minnesota, largely because of the increasing prevalence of grassland ecosystems in the western and southern part of the region.

Methods

Samples were prepared, cross-dated and measured following standard dendrochronological techniques (Stokes and Smiley, 1968). Empirical orthogonal function (EOF) analysis (North et al., 1982; Peixoto and Oort, 1992) was used to identify the dominant modes of variability present in the ringwidth network. The EOF analysis was repeated several times to determine the sensitivity of the final results to the choice of 1) detrending method, 2) the interval used for analysis (and associated spatial coverage of the tree-ring network), and 3) the application of the EOF technique. Potential relationships between annual tree growth and climate variables were assessed using correlation and response functions (Fritts, 1976) generated using DENDROCLIM2002 (Biondi and Waikul, 2004). In this program, bootstrapped confidence intervals are determined by shuffling the matrix of climate data 1000 times and calculating the 95th percentile range of the coefficients obtained from the randomized data.

Results

Chronology characteristics

Most ringwidth chronologies in the Winnipeg River region are between 100 and 170 years long. The median length of record recovered from a single tree is roughly 155 years. The oldest tree in the network is a 353 year old red pine, a sample of which was collected by H. Fritts at the Seagull Lake site in the Boundary Waters Canoe Area in 1971; if this tree is still alive, it is nearly 400 years old. The oldest tree in the Canadian portion of the Winnipeg River region is a 334 year old red pine, a sample of which was collected by M. Girardin at Sowden Lake in 2001. Only four sites have median tree ages greater than 200 years, and all are developed from red pines: Clay Lake and Sowden Lake in Ontario, and Seagull Lake and Saganaga Lake in Minnesota. The lesser ages of white pine stands are at least partially due to that species' tendency to exhibit heart-rot, as the innermost rings of white pines were often rotten and could not be sampled with an increment borer. Consequently, the ages shown here should be interpreted as minimum estimates of tree age only, especially for white pines.

Climate-ringwidth relationships

Regional tree growth is related to three independent climate signals (summer temperature, summer precipitation and growing-season length), but the correlations between tree growth and any single climate parameter are relatively modest. Significant correlation coefficients range between 0.2 and 0.4, and are not increased by aggregating monthly observations over longer intervals (2–4 month averages). There is some indication that regional tree growth responds differently to summer (June–July) temperature and precipitation conditions depending on the state of the other variable (Figure GS-14-2). Regional tree growth is more strongly influenced by summer precipitation when summer

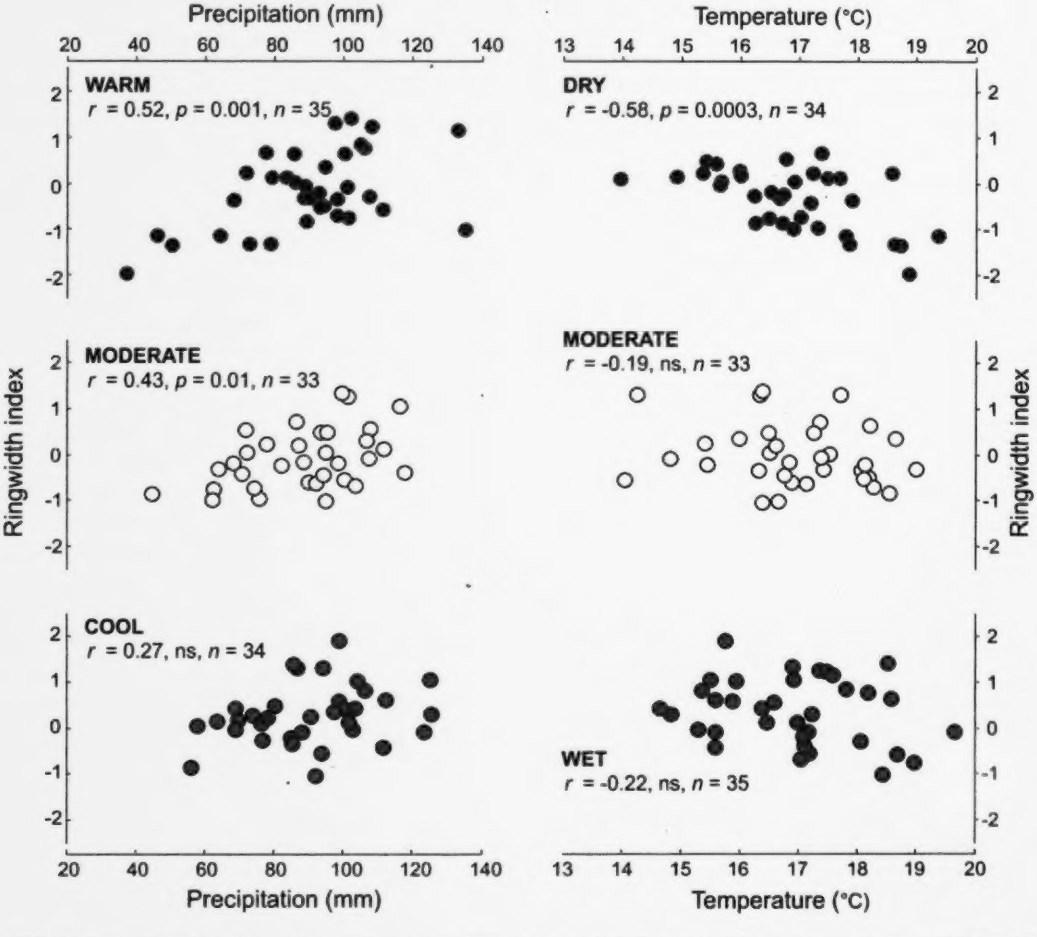

Figure GS-14-2: Scatterplots comparing regional ringwidth with precipitation (left side) and temperature (right side) during summer. In each frame, the observations of ringwidth and the climate parameter are selected based on the state of the other climate variable. For example, in the WARM case, ringwidth is compared to precipitation using only those years where summer temperatures were in the top tercile of their distribution. The DRY case plots ringwidth and temperature data during years with low summer rainfall (precipitation in the bottom tercile). Note: r, correlation coefficient; p, significance level; ns, not significant; n, number of observations.

temperatures are warm (in the upper tercile of its distribution). The correlation between precipitation and ringwidth is highest during warm summers, lower when summer temperatures are moderate and nonsignificant for cool summers. Similarly, ringwidth has a significant negative correlation with temperature only when summer precipitation is low (DRY) and is not significantly correlated when precipitation is either moderate or high. However, the correlation coefficients from the WARM and COOL cases are not significantly different from each other, and the coefficients for the DRY and WET cases are significantly different only at the 0.08 significance level.

Discussion

Although macro-scale climate variability is the most likely cause of the dominant regional growth pattern, the relationship between regional tree growth and any single climate variable is relatively weak. High growth is associated with long growth seasons and cool, wet summers, but the correlations between ringwidth and climate are not high enough to develop a traditional, regression-based dendroclimatic reconstruction (Fritts, 1976; Bradley, 1999). Because of these limitations, we focus our interpretation on the general relationship between summer climate conditions and the terciles of tree growth. As shown previously, high growth is commonly associated with cool temperatures and high rainfall, while low growth usually coincides with hot, dry summers. Therefore, we argue that regional ringwidth can be interpreted as a proxy record of past summer climate conditions in the Winnipeg River region, and classify years as either warm and dry (bottom tercile of ringwidth), cool and wet (upper tercile) or indeterminate (middle tercile).

This classification scheme provides some indication that summer drought may have been more persistent in the Winnipeg River region during the 19th century (Figure GS-14-3a). The 20th century has only one case (1946–48) where the region was in the warm/dry state for three consecutive years. This condition is more common in the earlier part of the record, as it happened four times in the 1800s (1829–31, 1839–41, 1862–64 and 1888–90) and once near the beginning of the record (1790–93). Persistent cool and wet conditions occur much less frequently, with only two cases in the entire record (1951–53 and 1999–2001). Applying the same classification after filtering to emphasize variations at decadal timescales indicates that the 1880s and 1890s had the longest run of warm, dry summers in the last 220 years (Figure GS-14-3b). This dry interval falls within an extended period of frequent forest fires from the 1870s to the 1920s identified by Suffling and Speller (1998) from the Hudson's Bay Company journal at Osnaburgh House (located immediately northeast of the Winnipeg River basin). The 1950s and 1960s had the longest-lasting period of cool and wet summers, with similarly persistent conditions observed in the 1850s. Determining the magnitude of climatic extremes in the pre-instrumental period is difficult because of the weakness of the relationship between tree growth and summer climate. However, because the years of both highest (1965) and lowest (1910) growth since 1783 AD occurred during the 20th century, we conclude that there is no evidence that summer climate was more extreme in the 19th or late 18th century.

In general, archival evidence from northwestern Ontario corroborates the tree-ring based classification of summer climate conditions during the early 19th century (Rannie, 2006). The Lac la Pluie post (near present-day Fort Frances, Ontario) was established by the North West Company in 1791, but its archives do not contain any entries that mention climate conditions until after the post was taken over by the Hudson's Bay Company in 1821. Although the post remained in operation until 1903, its

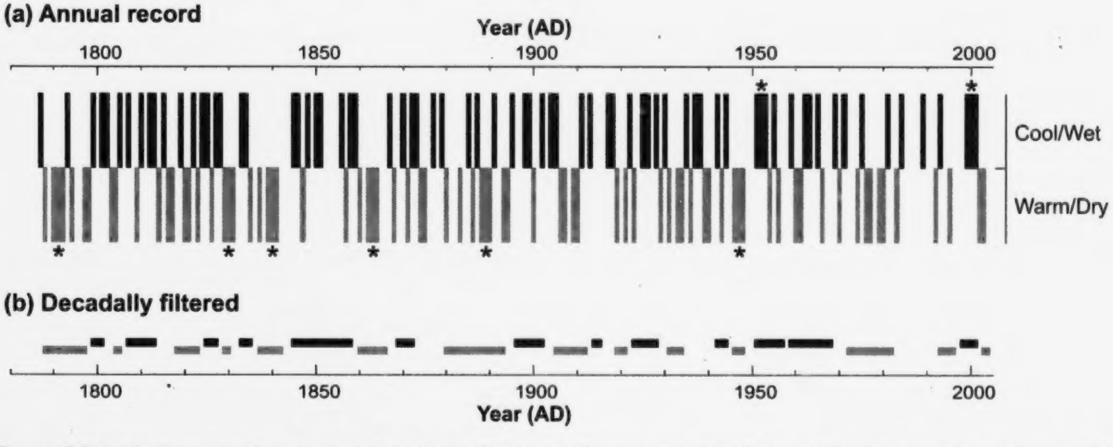

Figure GS-14-3: *Summer climate conditions in the Winnipeg River region, Manitoba, inferred from regional tree growth, 1783 to 2004 AD. Asterisks mark cases where climate is in the same state for three consecutive years. The lower plot is smoothed to highlight decadal variability, and is scaled to the proportion of variance in the tree-ring record at those timescales.*

archives were not maintained after 1841. Rannie (2006) identified seven "wet summers" within that 20-year period based on entries from the Lac la Pluie journal: 1824, 1825, 1827, 1828, 1830, 1832 and 1834. With one exception (1830), these years are classified as cool/wet based on the regional tree-ring record. The historical and tree-ring records also agree that there were no notably cool or wet summers between 1835 and 1841. However, there are no historical accounts that support the inference based on tree rings that the summers of 1822 or 1833 were cool and wet.

Conclusion

Although the cool, moist climate of the Winnipeg River area make it an important generating region for runoff, these same characteristics cause regional tree-ring records to contain a relatively weak, multivariate climate signal. Ringwidth data for this region contain a mixture of (sometimes competing) influences of temperature and precipitation during the growth season. However, the absence of a strong linear correlation with a single climate variable does not mean that tree growth in this region is not sensitive to climate. Instead, the climatic factors that limit growth are multivariate and likely change in importance from year to year. A common climatic influence remains the most likely factor responsible for the strong coherence in tree growth in multiple tree species across the region since the late 18th century. High and low growth across the region is associated with significantly different summer weather during the instrumental period, and this general relationship is supported by comparisons with archival records from early 19th century fur-trading posts. Therefore, even given the above limitations, this dataset still provides useful information about summer climate in this area since 1783 AD.

The tree-ring record suggests that summer droughts were more persistent in the 19th and late 18th century, with several instances of warm and dry conditions lasting for three consecutive years. Variability over longer timescales is also more prominent in the 19th century, with the longest interval of warm, dry summers in the last 220 years occurring in the 1880s and early 1890s. Estimating the magnitude of droughts inferred from the tree-ring record is more difficult, but because regional tree growth was at its lowest in 1910, we conclude that there is no evidence that drought was more extreme prior to the onset of direct monitoring.

Economic considerations

Since 2003, the Geological Survey of Canada, in co-operation with the Manitoba Geological Survey and the University of Arizona, has been working to understand changes in hydrology and climate in the watersheds used to generate hydroelectricity in Manitoba. In 2006/2007, hydroelectricity generated in Manitoba had a commercial value of roughly $1.8 billion (Manitoba Hydro, 2007). As with most hydropower operations, hydrological variability is the primary factor that influences year-to-year changes in the amount of energy produced at hydroelectric generation facilities and consequently, net income at Manitoba Hydro.

This research program has demonstrated that, unlike most regional rivers, river flow in the Winnipeg River system increased during the 20th century, with most of the gains occurring between 1920 and 1960 (St. George, 2007). This work has also shown that severe low flows are caused by a specific sequence of climatological 'events'; understanding this sequence may help improve forecasts of hydrological conditions several months in advance. For a longer perspective, tree-ring records from the Winnipeg River basin and the broader Prairie region have been used to estimate drought conditions in the Manitoba Hydro watershed during the last several hundred years. One of the principal goals of long-term planning at Manitoba Hydro is to ensure that their generating system can satisfy forecast energy demands under flow conditions equivalent to the lowest observed inflows. The period of lowest observed flows in the Manitoba Hydro system is described as the 'critical period', and is currently defined as the interval from 1939 to 1941. Drought records derived from tree rings provide a longer perspective that can be used to compare the 1939–41 event to other droughts from the recent past, and provide alternative worst-case scenarios for hydroelectric power production in Manitoba.

Acknowledgments

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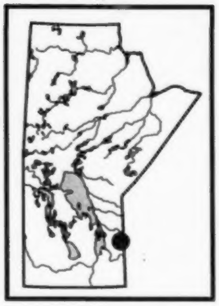
GS-15 Revegetation of tailings at the Gunnar minesite, Manitoba (NTS 52L14): plant growth in tailings amended with paper-mill sludge

by S. Renault[1], J. Markham[1], L. Davis[1], A. Sabra[1] and C. Szczerski[1]

Renault, S., Markham, J., Davis, L., Sabra, A. and Szczerski, C. 2007: Revegetation of tailings at the Gunnar minesite, Manitoba (NTS 52L14): plant growth in tailings amended with paper-mill sludge; *in* Report of Activities 2007, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 161–165.



Summary

A small-scale field experiment was designed in 2007 to test the effects of rototilling, fertilizing, microbial inoculation and amending Gunnar tailings with paper-mill sludge on plant establishment and growth. Microbial inoculation of some plants, such as pine, seems to have improved their survival rates in the absence of paper-mill sludge. Although the amendment of tailings with paper-mill sludge and fertilizer improved the growth of willow and tamarack, there was no significant effect of paper-mill sludge on plant survival and grass cover. The results suggest that the wet conditions in the spring of 2007 partly diminished the beneficial effect of paper-mill sludge and fertilizer on plant growth demonstrating that the drainage of tailings should be taken into account during revegetation of mine tailings.

Introduction

The tailings from the Gunnar gold mine in Nopiming Provincial Park (lat. 50°51.37′, long. 95°15.31′) are located in a depression south of the mine and cover approximately 11 ha (Slivitzky, 1996). Half of the tailings have been revegetated by natural succession, whereas the rest of the tailings are only sparsely vegetated in cracks and on accumulated organic debris. The tailings are relatively neutral with the pH ranging from 6.4 to 8.1 (Slivitzky, 1996; Londry and Sherriff, 2005). The surface water of the tailings was not found to contain significant amounts of metals or cyanides (Slivitzky, 1996), although the concentrations of copper, arsenic and cyanide in the tailings have been found to exceed the Canadian Interim Remediation Criteria for Soil (CIRCS) agricultural and/or residential/parkland guidelines in some areas of the tailings (Slivitzky, 1996).

In previous studies with Central Manitoba (Au) mine tailings, it has been shown that the addition of amendments (fertilizer and paper-mill sludge) improve the growth of plants by increasing the aeration and organic matter content, and improving the water and oxygen availability (Renault et al., 2004; Renault and Green, 2005; Green and Renault, in press). A preliminary field experiment conducted in 2006 at the Gunnar minesite has shown that the addition of paper-mill sludge to tailings can improve plant growth and reduce the effects of environmental stress (Renault et al., 2006). A greenhouse experiment also showed that inoculating alders (*Alnus sp.*) with nitrogen-fixing bacteria initially increased plant mortality but then increased subsequent plant growth (Markham, 2005). In the same experiment, inoculating alders with ectomycorhizal fungi (*Paxillus involutus*) also increased plant growth but to a lesser extent. A field planting of alders confirmed that pre-inoculation with nitrogen-fixing bacteria is essential for increased performance.

Objectives

The objective of the study is to conduct a small-scale experiment to determine the effects of paper-mill sludge and fertilizer on the establishment and growth of grasses, plants, shrubs and trees species in Gunnar tailings. We also found that black spruce (*Picea mariana*) growing on the site had an endophytic bacterium in their roots. We therefore wanted to determine if this bacterium would increase the performance of conifers planted on the tailings. The long-term goal is to provide recommendations for the revegetation of mine tailings in Manitoba.

Materials and methods

In May 2007, four experimental plots (2.5 x 10 m) were randomly selected on an unvegetated section of the Gunnar mine tailings. Each experimental plot was divided into three (0.5 x 10 m) subplots (control, fertilizer and paper-mill sludge with fertilizer treatment) and rototilled to a depth of 15 cm. No amendment was applied to the control subplot. The fertilizer subplot from each replicate received a treatment of 1400 kg/ha of fertilizer (10-3-6, N-P-K), and the last subplot was amended with both fertilizer and paper-mill sludge at a rate of 1400 kg/ha and 5.6 kg/m^2, respectively. Following application of the amendments, the subplots were rototilled again. Tailings samples were taken from between the subplots in May for analysis (conductivity, pH, phosphorus, nitrogen and organic matter). A portion of each of the 12 subplots was sown in June, one week after preparing the treatments, with a seed mixture of 20 kg/ha tall wheatgrass (*Agropyron elongatum*), 20 kg/ha alfalfa (*Medicago sativa*) and 20 kg/ha red fescue (*Festuca rubra*). Each subplot was also vegetated with inoculated and non-inoculated Jack pine (*Pinus banksiana*), black spruce (*Picea mariana)* and green alder (*Alnus viridis* ssp. *crispa*). The pine and spruce were inoculated with a culture of the rhizobacteria, isolated from *P. mariana* roots (8 x 10^6 cells), that was injected from cell suspension into the rooting zone or with a culture of *Paxillus involutus* that was previously shown to increase plant growth on the Central Manitoba mine tailings (Markham, 2005). This inoculation was carried out by placing agar blocks of the culture next to fine roots. The alders were inoculated with a crushed nodule suspension of green alder nodules collected from the region. Red osier dogwood (*Cornus sericea*), willow (*Salix*), tamarack (*Larix laricina*), fir (*Abies*) and coneflower (*Echinacea purpurea*) seedlings were also planted (Figure GS-15-1). Mine tailings samples were taken from each of the subplots in July for analysis.

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The exchangeable phosphorus of the samples was measured using the Olsen's extraction method (Kalra and Maynard, 1991). The conductivity of the tailings was measured using the 1:1 (v/v) water slurry method (Schofield and Taylor, 1955) and recorded with a Traceable™ Portable Conductivity Meter and Accumet pH meter (Fisher Scientific). The organic matter was measured with the loss-on-ignition (Kalra and Maynard, 1991). In September 2007, plant establishment, growth and injury/stress were assessed. Tailings samples were collected in each plot for determination of bulk density and element content (analysis will be done in the autumn of 2007).

Results and discussion

In May 2007, we made observations of the 2006 experimental plots. Some plants, including alfalfa, red fescue, slender wheatgrass (*Agropyron trachycaulum)* as well as red osier dogwood, were growing in the 2006 plots amended with paper-mill sludge while very little growth occurred in the control plots (Figure GS-15-2; see Renault et al., 2006, for experimental design). However, by the end of the season some of the plants were suffering from stress, mainly the red osier dogwood, suggesting that the amount of fertilizer used in 2006 may not have

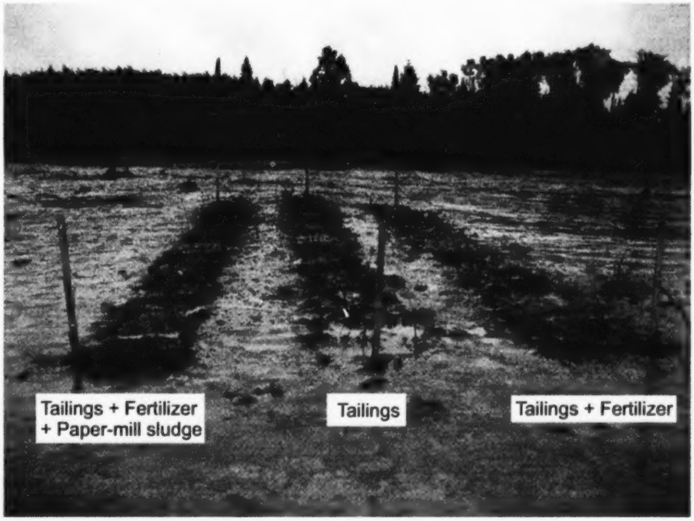

Figure GS-15-1: *Experimental plot (control, fertilizer and paper-mill sludge with fertilizer) at Gunnar minesite, Manitoba, in June 2007.*

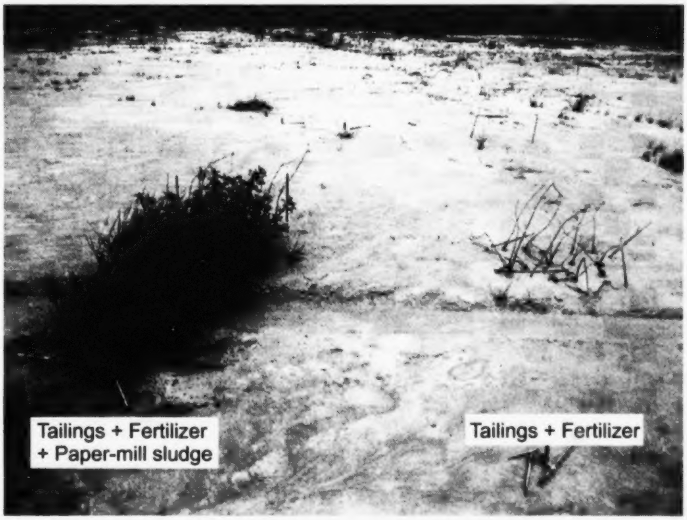

Figure GS-15-2*: Experimental plot 2006: plants growing in tailings with fertilizer and in tailings amended with paper-mill sludge and fertilizer, at Gunnar minesite, Manitoba, in May 2007.*

been sufficient.

Survival rates of the grasses and seedlings in the 2007 plots are summarized in Table GS-15-1. Unlike in 2006, the results of the 2007 experiment showed no significant difference in grass cover and seedlings (tamarack, willow, red osier dogwood and coneflower) survival between the treatments. This was mainly due to the high variability in the results between the four replicates. Replicate 1 had no grass growing in any of the treatments while replicate 2 had results similar to the 2006 season (Figure GS-15-3). Although, overall the survival results did not show a beneficial effect of the amendments, tamarack and willow seedlings (Figure GS-15-4) growing in tailings amended with paper-mill sludge and fertilizer were larger than the plants growing in the unamended tailings suggesting that the addition of paper-mill sludge and fertilizer can improve plant growth. Overall survival of the inoculated plants was poor. None of the alders survived and only two of the rhizobacteria-inoculated spruce (on the paper-mill sludge amended plots) survived. However, survival of the rhizobacteria-inoculated pine was significantly increased in the control and fertilizer plots compared to non-inoculated plants. On the paper-mill sludge amended plots there was no effect of inoculation on plant survival.

Analysis of the tailings samples collected in May and July revealed that the addition of fertilizer and paper-mill sludge did not significantly increase the organic matter, nitrogen or phosphorus content of the tailings (Table GS-15-2). This result is likely due to the wet conditions in the tailings during site preparation and planting, as well as the heterogeneity of the tailings. A larger scale experiment is required to increase the sample size. It was observed that the beneficial effect of rototilling (Szczerski, 2007) and paper-mill sludge addition (Green and Renault, 2007) to limit compaction was partly diminished by the high amount of precipitation in May and June, 2007. The addition of amendments was not sufficient enough to prevent the oxygen deficiency that limited plant survival and growth. Furthermore, leaching of nutrients could have occurred in the wet tailings and limited plant growth.

These results suggest that to revegetate mine tailings sites proper drainage of the tailings should be considered. Furthermore, to determine the suitability of paper-mill sludge as an amendment, a larger scale field study should be undertaken at the Gunnar minesite.

Economic considerations

Reclamation of land impacted by the extraction of natural resources is a current challenge for the government and industry. Fundamental revegetation techniques such as seedbed preparation, fertilization and seeding

Table GS-15-1: Survival of seedlings and grasses growing in amended tailings for three months, Gunnar minesite, Manitoba, summer 2007. The values represent the means of four replicates plus or minus the standard error.

Plant/shrub/tree	Control plot (tailings)	Fertilizer-amended plot	Sludge- + fertilizer-amended plot
		Cover (%)	
Grasses	3.8 ± 1.4	7.5 ± 3.1	10.9 ± 6.9
Alfalfa	0	0	0
		Survival (%)	
Red osier dogwood	50 ± 24	37.5 ± 25	62.5 ± 19
Willow sp	44 ± 18	50 ± 24	87 ± 14 (larger plants)
Tamarack	76 ± 17	32 ± 21	54 ± 12 (slightly larger plants)
Fir	0	0	0
Coneflower	12 ± 10	38 ± 28 (less chlorosis)	38 ± 28
Control alder	0	0	0
Inoculated alder	0	0	0
Control pine	12.5 ± 7.9	8.5 ± 4.9	25 ± 16
Paxillus involutus-inoculated pine	12.5 ± 7.9	37.8 ± 17.0	20.8 ± 7.9
Rhizobacteria-inoculated pine	45.8 ± 18.5	25.0 ± 16.0	12.5 ± 7.2
Control spruce	0	0	0
Paxillus involutus-inoculated spruce	0	0	0
Rhizobacteria-inoculated spruce	0	0	8.3

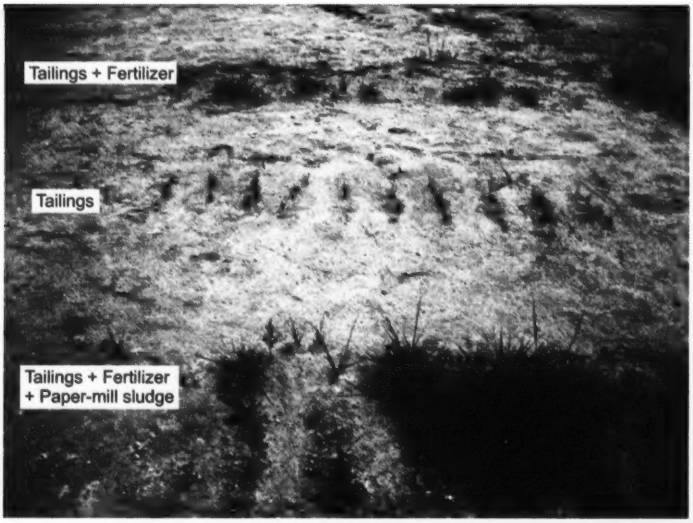

***Figure GS-15-3:** Grasses growing in unamended tailings, tailings amended with fertilizer and tailings amended with paper-mill sludge and fertilizer at Gunnar minesite, Manitoba, in September 2007.*

are often times inadequate for successful revegetation of mine tailings (Munshower, 1994). Research oriented toward using readily available amendments, such as paper-mill sludge, to increase revegetation success on such sites would benefit the paper-mill industry, mining industry as well as the government and future land users.

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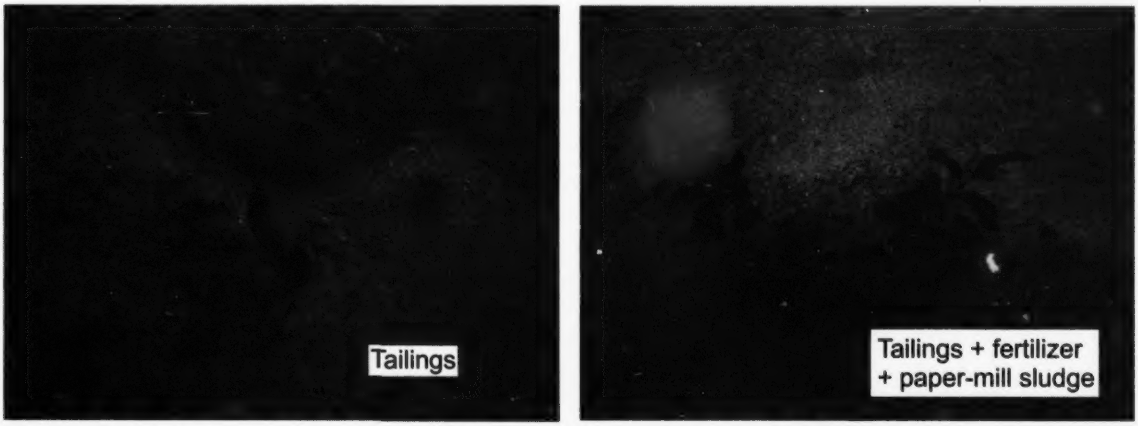

***Figure GS-15-4:** Willow growing in unamended tailings and in tailings amended with paper-mill sludge and fertilizer at Gunnar minesite, Manitoba, in September 2007.*

Table GS-15-2: Tailings analysis prior to treatments and post treatments. The values represent the means plus or minus the standard error of four replicates. Note, there is no significant difference between untreated and treated tailings.

	Control plot (tailings)	Fertilizer-amended plot	Sludge- + fertilizer-amended plot
May 2007 (prior to treatment)			
Conductivity (mS/m)	287 ± 38		
pH	8.15 ± 0.07		
Phosphorus (ppm)	0.65 ± 0.31		
Nitrogen (ppm)	9.91 ± 2.67		
Organic matter (%)	1.92 ± 0.24		
July 2007 (post treatment)			
Conductivity (mS/m)	360 ± 68	430 ± 57	346 ± 75
pH	8.33 ± 0.11	8.46 ± 0.07	8.32 ± 0.13
Phosphorus (ppm)	1.26 ± 0.64	2.94 ± 1.94	1.50 ± 0.81
Nitrogen (ppm)	8.2 ± 4.0	4.9 ± 1.7	6.5 ± 1.7
Organic matter (%)	2.54 ± 0.24	2.55 ± 0.16	3.01 ± 0.20

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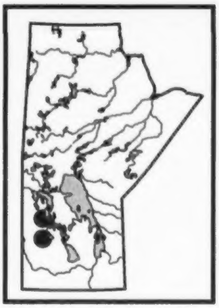
GS-16

Manitoba Geological Survey's Stratigraphic Corehole Drilling Program, 2007 (parts of NTS 62N1, 16, 63C1)

by J.D. Bamburak



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Summary

Under the 2007 Stratigraphic Corehole Drilling Program of the Manitoba Geological Survey (MGS), a total of three coreholes were drilled. Two of the coreholes were drilled west of Lake Winnipegosis and one, west of Dauphin. Corehole M-1-07, completed to a depth of 125.2 m, penetrated possible 'hydrothermally altered dolomite' (or hydrodolomite) within the upper part of the Silurian Interlake Group, beneath the Devonian Ashern Formation. Corehole M-2-07, drilled to 29.7 m, succeeded in obtaining a more complete recovery of sulphide mineralized core from the upper part of the Souris River Formation, than in previous drilling at this site. A third corehole (M-3-07) was drilled west of Dauphin to a depth of 11.2 m within Cretaceous shale of the Favel and upper Ashville formations. The drillcore indicated that altered (burnt) shale, found in outcrop in the bank of the Valley River, does not extend into the subsurface to the east and is probably a localized geological feature.

The recognition of hydrodolomite in the province would provide the incentive for Mississippi Valley-type metallic mineral investigations and for oil and gas exploration in southwestern Manitoba.

Introduction

The Manitoba Geological Survey (MGS) 2007 Stratigraphic Corehole Drilling Program continued investigations in the Duck Bay and Wellburns Creek areas of west-central Manitoba. This complements work originally started in 2006 (Bamburak, 2006). Two coreholes (M-1-07 and M-2-07; Figure GS-16-1) were drilled into Devonian and Silurian dolomite as detailed in Table GS-16-1.

An additional corehole (M-3-07) was drilled to a depth of 11.2 m into Cretaceous shale (Table GS-16-1). This corehole was drilled near the east bank of the Valley River, west of Dauphin (Figure GS-16-1).

Duck Bay

The community of Duck Bay is situated on the west shore of Lake Winnipegosis, approximately 20 km north of Camperville, and on the northern end of PR 272 (Figure GS-16-2). In 2006, corehole M-1-06 was drilled on the southern margin of the community to a depth of 75.4 m, ending in the Devonian Ashern Formation (Figure GS-16-3). The original target of the 2006 drilling was the karstified top of the Silurian Interlake Group but the hole had to be abandoned prematurely due to sand infill. In early August 2007, a second attempt resulted in the successful completion of corehole M-1-07 (Figure GS-16-1, Table-GS-16-1) to a depth of 125.2 m, ending within the Interlake Group.

Examination of core from M-1-07 (Table GS-16-1) reveals contrasting textures. Above the argillaceous Ashern Formation, the core shows typical Winnipegosis Formation dolomite. In contrast, the core below the Ashern Formation and a major unconformity indicates that several of the upper Interlake Group beds have been distinctly altered, in addition to karst development. The alteration consists of abundant dark grey and white mottles with blue-green argillic veinlets, believed to be characteristic of 'hydrothermally altered dolomite' or hydrodolomite. Some of the beds are also vuggy and very soft, and contain very fine grained black sulphides. The core from M-1-07 has been split and half of the core crushed and sent for instrumental neutron activation analysis (INAA) and inductively couple plasma (ICP) analysis.

Wellburns Creek (formerly Point River)

In August 2006, corehole M-2-06 was completed south of PR 271, immediately east of a tributary to Wellburns Creek (formerly Point River) west of Lake Winnipegosis (Figure GS-16-2). The corehole reached a depth of 90.7 m and ended within the Devonian Upper Member of the Winnipegosis Formation (Figure GS-16-3). Bamburak (2006) reported that a possible sphalerite/galena grain was present within a fracture shear within the Second Red Beds of the Dawson Bay Formation at a depth of about 72.8 m. Scanning electron microscopy (SEM) and energy-dispersive X-ray spectrometry (EDS) analyses of the grain by J. Young of the Department of Geological Sciences at the University of Manitoba confirmed the grain was sphalerite and that there is also abundant sphalerite present on the slickensides of the fracture surface (J. Young, pers. comm., 2007).

The presence of sphalerite crystals in corehole M-5-00, drilled near the east end of PR 271 (Figure GS-16-2), was reported by Bamburak et al. (2000) and Bamburak (2006). X-ray diffraction (XRD) confirmation of this identification was received from J. Young of the Department of Geological Sciences at the University of Manitoba (J. Young, pers. comm., 2007). In addition, the XRD analysis indicated the presence of minrecordite ($CaZn(CO_3)_2$) and stilleite (ZnSe) in the core sample.

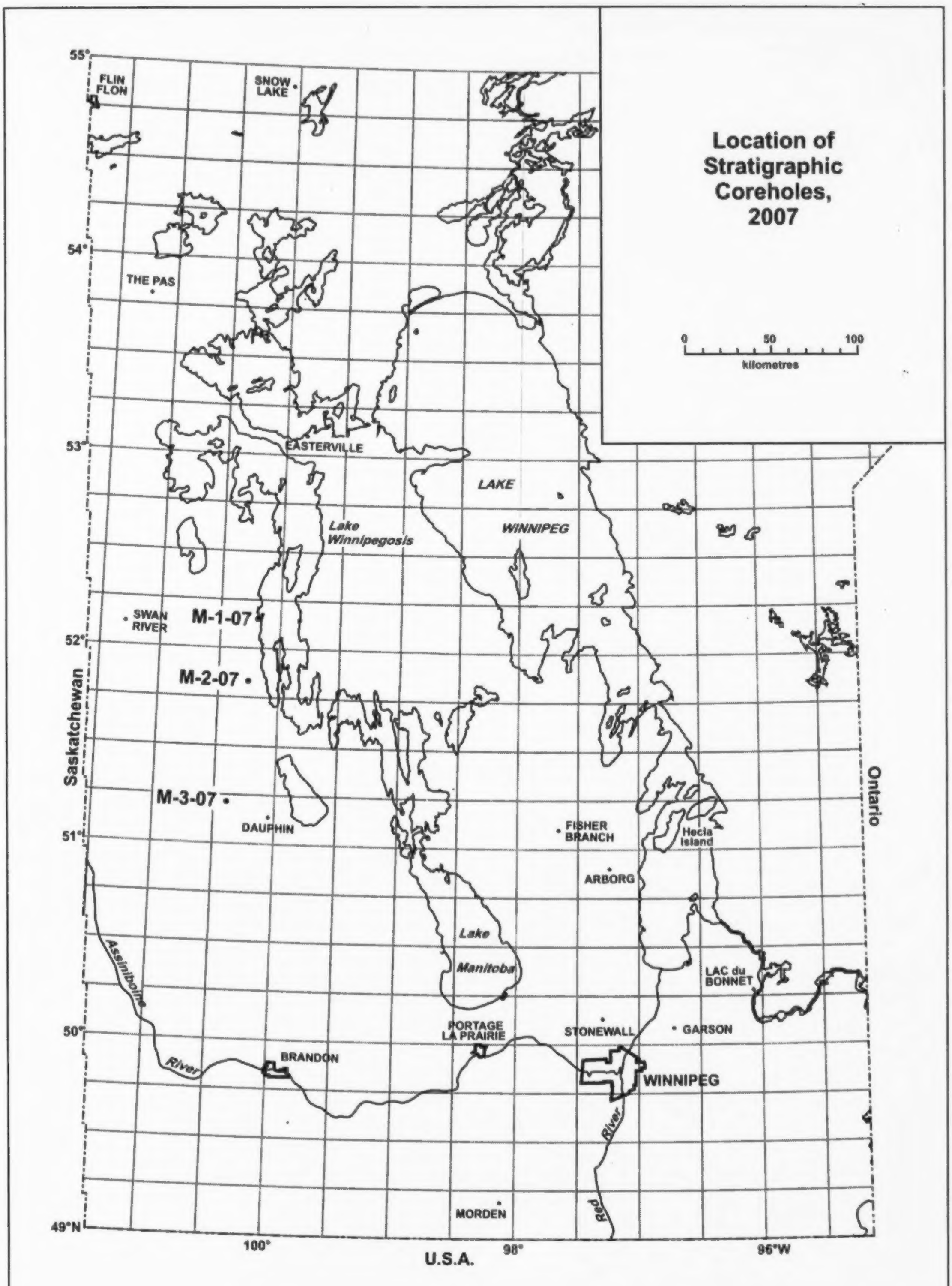

Location of Stratigraphic Coreholes, 2007
0
50
100
kilometres
55°
54°
53°
52°
51°
50°
49°N
100°
98°
96°W
U.S.A.
Saskatchewan
Ontario
FLIN FLON
SNOW LAKE
THE PAS
EASTERVILLE
LAKE
WINNIPEG
Lake Winnipegosis
SWAN RIVER
M-1-07
M-2-07
M-3-07
DAUPHIN
FISHER BRANCH
Hecla Island
ARBORG
Lake
Manitoba
LAC du BONNET
PORTAGE LA PRAIRIE
STONEWALL
GARSON
BRANDON
WINNIPEG
Assiniboine
River
Red
River
MORDEN

Figure GS-16-1: Location of Manitoba Geological Survey's stratigraphic coreholes, 2007.

Table GS-16-1: Summary of Manitoba Geological Survey stratigraphic corehole data, 2007.

Hole no.	Location and elevation (m asl)	SYSTEM/Formation/ (Member)	Interval (m)	Lithology summary
M-1-07	08-30-36-19W	DEVONIAN/ Winnipegosis/ (Upper)	0.0–61.4	Reef facies, dolomite, buff, well defined bedding with numerous horizontal fractures near top, good to excellent fine vuggy (birdseye) porosity with zebra-like textures and specks of black sulphides between 46.5 and 61.0 m
Duck Bay South	5774977N 421088E	(Lower)	61.4–71.7	Platform facies, dolomite, buff, mottled, massive near top, pin-point porosity near base, and sand infill near middle and base
	258	Ashern	71.7–80.1	Dolomite, argillaceous and shale, greenish and red mottled
		SILURIAN/Interlake Group (possibly Cedar Lake Formation at top)	80.1–125.2	Dolomite, buff with beds of porcellaneous, sugary or pinpoint porosity separated by four intervals of hydrothermally altered(?) dolomite with dark grey and white mottles and blue-green argillic veinlets; possible argillaceous marker bed between 122.5 and 123.1 m
M-2-07	02-04-33-20W	DEVONIAN/Souris River/ (Sagemace)	0.0–17.8	Limestone, beige, fine grained with small vugs, calcareous, black to buff limestone (oxidized along fractures) with black sulphides, sand infill at base
Wellburns Creek West	5739363N 415171E	(Point Wilkins)	17.8–26.6	Limestone, yellow and brown, sugary, vuggy, brecciated in part with black sulphide fracture surfaces; becoming argillaceous limestone with calcite-healed fractures at base
	280	(First Red Beds)	26.6–29.7	Shale, dark grey, breccia with disturbed bedding underlain by laminated brown and beige limestone; becoming laminated black and grey shale with polymict breccia and abundant black sulphides downward
M-3-07	13-35-25-21W	Overburden	0.0–3.1	Soil and till
Valley River East	5674213N 408115E	CRETACEOUS/Favel	3.1–7.2	Shale, dark grey to black, speckled, calcareous, horizontally bedded, with a few 2 mm thick gypsum laminae, minor petroleum smell
	335	Ashville (upper)	7.2–11.2	Shale, black, noncalaceous, greasy shale becoming darker downward

According to a University of Arizona webpage, minrecordite has been reported in a dolostone-hosted hydrothermal polymetallic ore deposit in Tsumeb, Namibia and from the wallrock of a carbonate-hosted Pb-Zn orebody in the Navan deposit, Ireland (University of Arizona, 2005).

During the drilling of corehole M-2-06 (Figure GS-16-2), core recovery was poor and the drilling mud showed evidence of particles of black mineralization. For these reasons, it was decided to redrill the site of corehole M-2-06 in 2007. Corehole M-2-07 (Figure GS-16-1, Table-GS-16-1) was drilled to a depth of 29.7 m. It had better core recovery with black sulphide mineralization finely disseminated throughout the core, from the Sagemace Member down into the First Red Beds of the Souris River Formation. The mineralization is also concentrated on numerous fracture surfaces. Because the nature of the very fine grained black sulphide mineralization is unknown, the core from M-2-07 has also been sent for INAA and ICP analysis.

Valley River

McCabe and Bannatyne (1970, Stop 13) described an "abnormal" shale outcrop along the Valley River, 18 km west-northwest of Dauphin (near corehole M-3-07, Figure GS-16-1). They described light buff and pink thin-bedded, fissile, speckled calcareous shale of the Cretaceous Favel Formation overlying pink to buff, greyish red, yellow and purplish red noncalcareous slabby to fissile shale of the Ashville Formation. The section was described as having been "highly oxidized" or "burned" relative to a patch of "unoxidized" black shale (of the Ashville Formation, Table GS-16-2), which is present laterally at the south end of the outcrop. McCabe and Bannatyne (1970) did not speculate on the origin of the altered shale but they did mention that the only other known outcrop "of a similar nature" is present on the southeast flank of the Porcupine Hills, where buff and pink weathered Favel Formation can be seen (now referred to as the Digger Don Roadcut, Field Trip Guidebook, Stop 11, McCabe and Bannatyne, 1970).

In June 2006, the Valley River northern outcrop (Table GS-16-3) was sampled by C. Lamb of Husky Energy Inc. during a field trip led by the MGS. Three samples (HE001–003) were collected and standard thin sections were prepared. The slides were double stained for carbonates and impregnated with blue epoxy. After thin-section photomicroscopy, the cover slides from samples HE002 and 003 were removed and the slides submitted for SEM and backscattered electron microscopy. Bulk and clay XRD analyses were conducted on

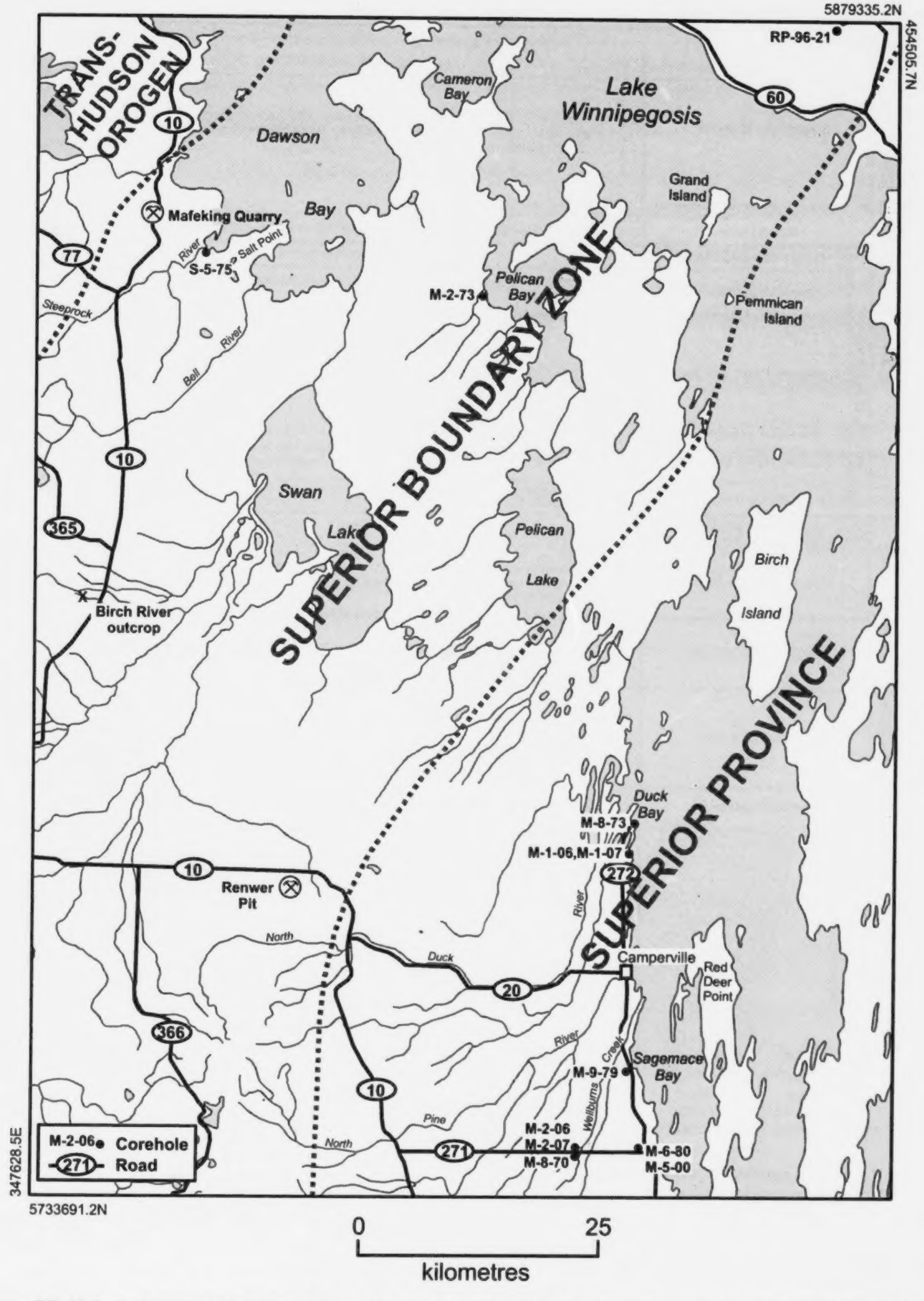
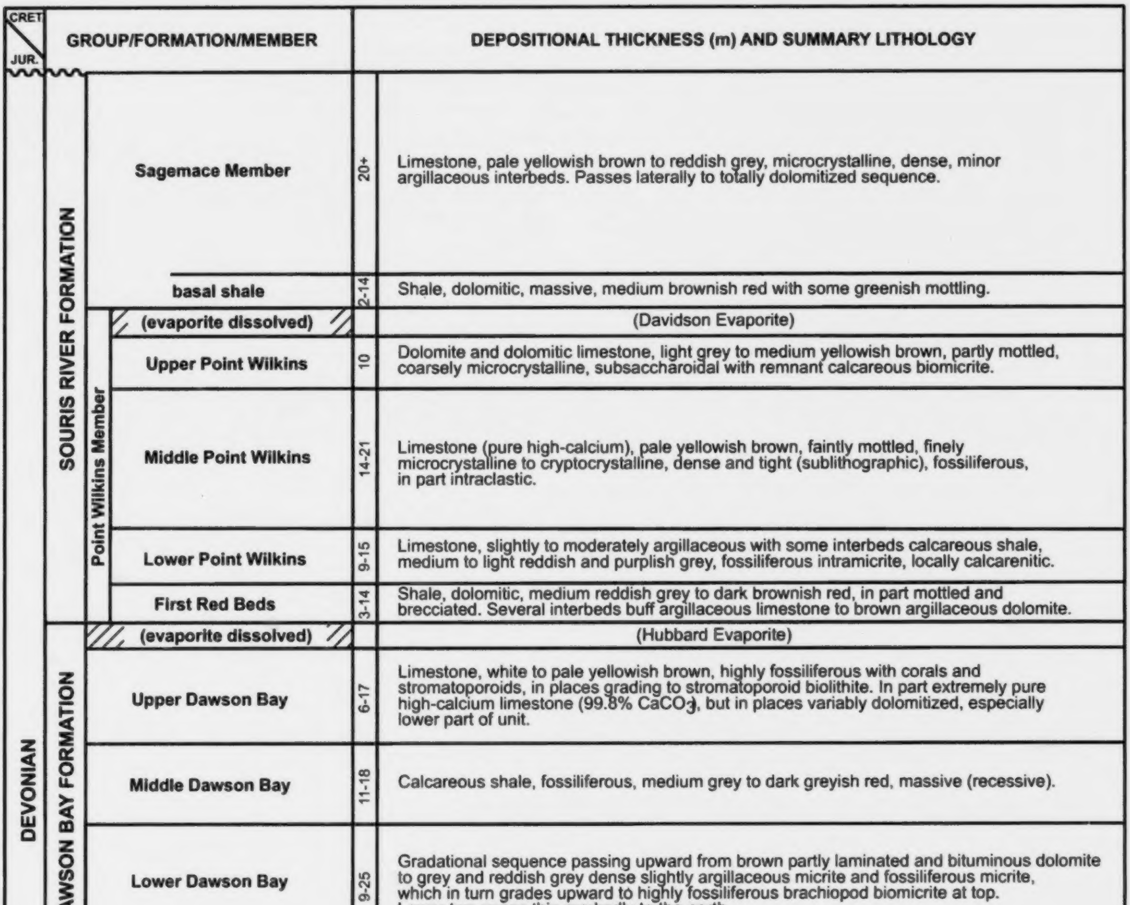

5879335.2N
454505.7N
347628.5E
5733691.2N
TRANS-HUDSON OROGEN
SUPERIOR BOUNDARY ZONE
SUPERIOR PROVINCE
Lake Winnipegosis
Cameron Bay
Dawson Bay
Grand Island
Pemmican Island
Birch Island
Pelican Bay
Pelican Lake
Swan Lake
Duck Bay
Red Deer Point
Sagemace Bay
Mafeking Quarry
Salt Point
Renwer Pit
Birch River outcrop
Camperville
Steeprock River
Bell River
North Duck River
Pine River
North
Wellburns Creek
River
RP-96-21
S-5-75
M-2-73
M-8-73
M-1-06,M-1-07
M-9-79
M-2-06
M-2-07
M-8-70
M-6-80
M-5-00
10
60
77
365
366
20
272
271
M-2-06 Corehole
271 Road
0
25
kilometres

Figure GS-16-2: Selected stratigraphic holes west of Lake Winnipegosis, Manitoba, and boundaries of Precambrian domains, including the Superior Boundary Zone (SBZ).



CRET / JUR.	GROUP/FORMATION/MEMBER			DEPOSITIONAL THICKNESS (m) AND SUMMARY LITHOLOGY	
DEVONIAN	SOURIS RIVER FORMATION		**Sagemace Member**	20+	Limestone, pale yellowish brown to reddish grey, microcrystalline, dense, minor argillaceous interbeds. Passes laterally to totally dolomitized sequence.
			basal shale	2-14	Shale, dolomitic, massive, medium brownish red with some greenish mottling.
		Point Wilkins Member	**(evaporite dissolved)**		(Davidson Evaporite)
			Upper Point Wilkins	10	Dolomite and dolomitic limestone, light grey to medium yellowish brown, partly mottled, coarsely microcrystalline, subsaccharoidal with remnant calcareous biomicrite.
			Middle Point Wilkins	14-21	Limestone (pure high-calcium), pale yellowish brown, faintly mottled, finely microcrystalline to cryptocrystalline, dense and tight (sublithographic), fossiliferous, in part intraclastic.
			Lower Point Wilkins	9-15	Limestone, slightly to moderately argillaceous with some interbeds calcareous shale, medium to light reddish and purplish grey, fossiliferous intramicrite, locally calcarenitic.
			First Red Beds	3-14	Shale, dolomitic, medium reddish grey to dark brownish red, in part mottled and brecciated. Several interbeds buff argillaceous limestone to brown argillaceous dolomite.
	DAWSON BAY FORMATION		**(evaporite dissolved)**		(Hubbard Evaporite)
			Upper Dawson Bay	6-17	Limestone, white to pale yellowish brown, highly fossiliferous with corals and stromatoporoids, in places grading to stromatoporoid biolithite. In part extremely pure high-calcium limestone (99.8% $CaCO_3$), but in places variably dolomitized, especially lower part of unit.
			Middle Dawson Bay	11-18	Calcareous shale, fossiliferous, medium grey to dark greyish red, massive (recessive).
			Lower Dawson Bay	9-25	Gradational sequence passing upward from brown partly laminated and bituminous dolomite to grey and reddish grey dense slightly argillaceous micrite and fossiliferous micrite, which in turn grades upward to highly fossiliferous brachiopod biomicrite at top. Lower two zones thin markedly to the north.
			Second Red Beds	6-15	Red to greenish grey dolomitic shale, commonly brecciated as a result of salt collapse.
	ELK POINT GROUP	WINNIPEGOSIS FORMATION	**PRAIRIE EVAPORITE**	0-129	Prairie Evaporite: dominantly salt with potash interbeds and minor anhydrite in basinal areas; entirely anhydrite in shelf areas (at present). Originally present throughout the entire Devonian outcrop belt, but subsequently removed by subsurface salt solution. Where preserved in subsurface, overlaps and completely buries Winnipegosis reefs with resultant thinning of evaporite section.
		Upper Winnipegosis	**(reef)**	0-90	Reefal facies: dolomite, very fine to medium crystalline, ranges from compact dense to subsaccharoidal, massive to medium/thick bedded, variably fossiliferous but texture largely obscured by dolomitization. Reef thicknesses tend to be relatively uniform in a given area.
			(inter-reef)	35	Inter-reef facies: dolomite, brown to black, finely laminated with black bituminous partings, in places calcareous. Lamination best defined towards top of unit.
			Lower Winnipeg-osis	10-20	Lower Winnipegosis: dolomite, fine to medium crystalline, moderately granular to saccharoidal, medium to thin bedded. In part calcareous and grades laterally to Elm Point limestone facies.
			ELM POINT FORM.	10-20	Elm Point: limestone, pale yellowish brown, dense, fine grained, biomicrite. In part shows lighter yellowish dolomitic mottling. Pure high-calcium limestone to calcareous dolomite.
			ASHERN FORMATION	3-18	Argillaceous dolomite and dolomitic shale, medium to dark greyish and brownish red, in places reduced to greenish grey. Local basal dolomite breccia.
SIL.	**INTERLAKE GROUP**				Dolomite, white to pale yellowish buff, mostly microcrystalline dense, thin bedded, sublithographic, in part stromatolitic. Some porous biostromal interbeds towards top.

*Figure GS-16-3: Detailed Devonian stratigraphic succession and lithology (*from *McCabe and Barchyn, 1982; Bezys and McCabe, 1996).*

Table GS-16-2: Mesozoic stratigraphy of the northern part of the Manitoba Escarpment (Bamburak, 1999).

Formation/Member	Maximum thickness (m)	Lithology
Upper Cretaceous		
Pierre Shale		
Odanah Member	150	hard grey siliceous shale
Millwood Member	60	soft bentonitic clay
Pembina Member	7	noncalcareous black shale with numerous bentonite interbeds near base
Gammon Ferruginous Member	5	ferruginous black shale
Carlile Formation		
Boyne Member	30	chalky buff and grey speckled calcareous shale
Morden Member	30	noncalcareous black shale with abundant jarosite
Favel Formation		
Assinniboine Member	17	olive-black speckled calcareous shale with Marco Calcarenite bed near top
Keld Member	17	olive-black speckled calcareous shale with Laurier Limestone bed near top
Ashville Formation	80	noncalcareous black to dark grey shale, silty; Newcastle sand zone, in places
Swan River Formation	150	sandstone, sand and silt, quartzose, pyritic and shale, noncalcareous

Table GS-16-3: Stratigraphy of Valley River northern outcrop, Manitoba, with Husky Energy Inc. samples.

Location: 13-35-25-21-W1, 5674326N, 408076E Elevation: 325 m asl at waterline	Thickness (m)
Overburden	
Recent alluvium, soil and vegetation	0.4
Pleistocene boulder pavement	0.1
Favel Formation	
Shale, orange and pink, thin bedded, fissile, calcareous	4.8
Pebble conglomerate, shale clasts, pink and grey, noncalcareous, with gypsum cement	0.14
Shale, yellow, laminated, calcareous **(Sample HE002)**	0.3
Upper Ashville Formation	
Shale, pink-red, slabby to fissile, noncalcareous **(Sample HE003)**	0.75
Shale, greenish buff, slabby to fissile, noncalcareous, with orange fractures (minor grey shale in small 1 m³ patch near base at south end of outcrop, Sample HE001)	2
Covered interval above waterline	
Rubble	1.5

all three samples using a Phillips XRG-3100 XRD system (Husky Energy Inc., 2007). The sample descriptions and results follow.

Sample HE001 – unaltered grey silty upper Ashville Formation shale

Sample HE001, noncalcareous grey silty shale of the Cretaceous upper Ashville Formation (Table GS-16-3), was collected near the base of the outcrop, at its south end. The 1 m^3 grey shale patch is laterally equivalent to enclosing altered or burnt noncalcareous greenish buff shale.

Thin section petrology, SEM and XRD analyses of Sample HE001 (Husky Energy Inc., 2007) showed that the unaltered silty shale is finely laminated and quartzose (62.0% of the bulk sample is composed of monocrystalline quartz silt grains). Illite comprises the entire clay fraction (13.5%). Also present are K-feldspar silt to sand (5.5%), gypsum (7.8%), anhydrite (4.0%), pyrite (7.2%), sulphate blebs and microscopic reddish iron-oxide particles.

Sample HE002 – altered yellow Favel Formation shale

Calcareous, yellow, laminated shale, from near the base of the Cretaceous Favel Formation, was collected from a conspicuous, and relatively massive, 0.3 m thick bed (Table GS-16-3) situated between thicker overlying and underlying fissile, reddish shale beds, near the centre of the outcrop (Sample HE002). The yellow shale is also found directly below a thin (0.14 m) pink and grey shale pebble conglomerate bed (which probably represents an unconformity). Although the conglomerate is not calcareous, it is still included within the Favel Formation.

According to Husky Energy Inc. (2007), Sample HE002 contains abundant gypsum (forming 31.6% of the bulk sample, as blebs and mineral cement within microscopic pores) and associated calcite (11.0%). Anorthite, in the form of fine laths, and andradite, as rounded crystals with rhombic to trapezoidal faces, constitute 46 and 11%, respectively, of the sample, determined by XRD analysis. Analyses of the yellow shale was performed by GR Petrology Consultants Inc. of Calgary and in their report they stated that "andradite forms as an alteration of siliceous limestone in regional and contact metamorphic environments" (Husky Energy Inc., 2007).

Sample HE003 – altered pink-red upper Ashville Formation shale

Sample HE003 was taken from a 0.75 m thick bed of altered noncalcareous pink-red shale from the Cretaceous upper Ashville Formation (Table GS-16-3), underlying the Favel Formation yellow laminated shale and overlying the upper Ashville Formation greenish buff shale (described above).

The pink-red shale contained in Sample HE003 comprised mainly quartz silt grains and amorphous silica that form 50.5% of the bulk sample. Also present are calcite (6.2%), dolomite (6.0%), anorthite (20.0%), pyrite (3.6%), hematite (6.6%) and ilmenite (2.6%). The clay fraction forms 4.5% of the bulk sample and consists of 87.5% mixed-layer illite-smectite clay and 12.5% illite (Husky Energy Inc., 2007).

Valley River east corehole

In August 2007, corehole M-3-07 (Figure GS-16-1) was drilled into Cretaceous shale of the Favel and upper Ashville formations (Table GS-16-2) to a depth of 11.2 m (Table GS-16-1), near the east bank of the Valley River, 18 km west-northwest of Dauphin. The corehole was designed to test whether alteration noted on the bank of the Valley River (described above) continues within the subsurface to the east.

Examination of the M-3-07 core indicates that Favel and upper Ashville formations in the core (Table GS-16-1) are unaltered black to grey, calcareous and noncalcareous shale similar to that seen at the base of the Valley River northern outcrop (Table GS-16-3) and in the eastern half of the Valley River southern outcrop (situated 200 m to the south). This suggests that the altered shale that can be seen in the banks of the Valley River is not widespread and only occurs in the vicinity of the present-day valley walls. It is also very likely that as erosion of the bank continues, a normal 'unaltered' shale bank will be revealed.

The Favel/Ashville formations core from M-3-07 seemed to have a minor petroleum odour that could be detected shortly after drilling (Table GS-16-1), which is consistent with historical studies (Bannatyne, 1970) that indicate the presence of oil shale along the Manitoba Escarpment. However, when the core was viewed under ultraviolet light several days later, no oil fluorescence could be seen. Total organic carbon (TOC) analysis of this core is scheduled for a future project.

Hydrothermal fluids

As indicated earlier, McCabe and Bannatyne (1970) did not indicate how the Valley River outcrop may have been altered, apart from mentioning that it "may represent a 'burned' section of highly oxidized Ashville and Favel beds." However, Bamburak and Nielsen (1996) provided at least five modes of origin for similarly formed scoriaceous clinker from the Cretaceous Favel Formation (Table GS-16-2) found in the Renwer gravel pit (Figure GS-16-2). Autocombustion of oil shale was the most favoured mode of origin by Bamburak and Nielsen (1996); however, in view of the Husky Energy Inc. (2007) suggestion (described above) of "regional and contact metamorphic" alteration possibly due to hydrothermal fluids, volcanic activity cannot be ruled out. It should be noted that Bezys et al. (1996) indicated the possible presence of a Cretaceous volcanic vent near Easterville (Figure GS-16-1) about 200 km to the north of the Valley River outcrop (near M-3-07, Figure GS-16-1) and within the SBZ. They stated that nonkimberlitic accretionary lapilli found, within Swan River Formation (Table GS-16-2) sediment, in Cominco RP-96-21 (Figure GS-16-2) drillcore likely originated from a volcanic vent within or adjacent to the SBZ, not more than 20 km from the drillhole. Gale and Conley (2000) and Bamburak (2006) concluded that basement reactivation within the SBZ likely induced vertical fracturing and faulting of overlying Phanerozoic beds that provided pathways for basement and interformational fluids. Likewise, these vertical fractures and faults may have been utilized as pathways by concurrent volcanic activity.

Hydrothermal fluid activity in southwestern Manitoba is also indicated by

- The possible recognition of hydrodolomite in the drillcore of M-01-07 (as described above).
- The discovery of the mineral minrecordite in the drillcore of M-5-00. As indicated earlier, minrecordite is associated with a dolostone-hosted hydrothermal polymetallic ore deposit in Tsumeb, Namibia (University of Arizona, 2005).

- The identification, by McCracken (1999), of hydrothermally altered conodonts in the argillaceous residue contained within chimney structures found within Devonian carbonate hostrock in the Mafeking Quarry (Figure GS-16-2). According to Fedikow et al. (2004), the chimney structures (which are also lined with siderite-rich rind and siliceous sinter) are interpreted to be paleobrine vents.
- Altered Marco Calcarenite, contained within the Assiniboine Member of the Cretaceous Favel Formation (Table GS-16-2), underlain by iron-oxide–bearing shale, found along the Birch River (Figure GS-16-2) by Bamburak (1999).
- Mississippi Valley-type mineralization found in coreholes (M-2-73, S-5-75, M-9-79, M-6-80 and M-5-00, Figure GS-16-2) drilled in the vicinity of the north basin of Lake Winnipegosis, as reported by Gale and Conley (2000) and Bamburak (2006).
- Mississippi Valley-type mineralization found in a Klyne Exploration drillhole, off the east shore of Pemmican Island in the north basin of Lake Winnipegosis (Figure GS-16-2). Analysis returned values of 4.59% Zn, 0.41% Pb and 0.014% Cu over 15 cm of the Silurian Interlake Group (Bamburak and Klyne, 2004).

As stated above, hydrodolomite is believed to be present in the karstified Silurian Interlake Group core from M-1-2007, below a major unconformity and the argillaceous Devonian Ashern Formation (Table GS-16-1) that formed a tight cap preventing upward movement of hydrothermal fluids. It should be noted that according to Campeau and Kissin (1988) and Kent (1999), hydrodolomite has been recognized in carbonate rock within the Meadow Lake Formation (equivalent to the Ashern Formation) in Saskatchewan, approximately 500 km northwest of M-1-2007. The hydrodolomite was found during an extensive drilling program carried out by Canadian Occidental Petroleum Limited (now Nexen Inc.) and Saskatchewan Mining Development Corporation, 24 km south of La Ronge.

Further, Christopher (1996) suggested that hydrothermal fluids, which may have altered the carbonate rock within the Meadow Lake Formation, could have increased the grade of the coals in the Lower Cretaceous Manville Group in Saskatchewan to sub-bituminous grade. The Manville Group is equivalent to the Swan River Formation (Table GS-16-2), which underlies the altered or burnt Ashville and Favel formations found in the Valley River outcrop (described above). A similar upward movement of hydrothermal fluids from the underlying Paleozoic beds along faults beneath the Valley River might account for the andradite mineralization, which was indicated in the Husky Energy Inc. (2007) study. Although the drilling of M-3-07 indicated that the burnt shale is probably a local feature, additional drilling is required before alteration by hydrothermal fluids can be completely discounted.

Economic considerations

The possible recognition of hydrodolomite in a MGS corehole drilled near Duck Bay would mark the first time that this rock type has been found in Manitoba. This discovery, if confirmed, is of major significance because it would indicate that warm to hot saline fluids have flowed through the Paleozoic stratigraphic sequence in southwestern Manitoba and had the ability to alter the country rock by increasing porosity and permeability. The leached limestone and dolomite could host metallic mineralization in fractures and voids, precipitated from the brines. These processes could explain the Mississippi Valley-type mineralization found offshore of Pemmican Island in the north basin of Lake Winnipegosis and other similar mineralization present at other sites in west-central Manitoba (Bamburak, 2006).

There is also the potential for the discovery of oil and gas reservoirs in Silurian and possibly older beds in southwestern Manitoba, due to the increased porosity and permeability that was induced by the hydrothermal fluids. Oil and gas migration may have occurred simultaneously with the movement of these hydrothermal fluids through the karstified Silurian Interlake Group, below the Devonian Ashern Formation argillaceous caprock. The best potential for oil and gas traps would be within fractures and faults induced by basement reactivation along the trend of the SBZ, or possibly up dip of the SBZ, within capped karst structures. The relationship between fault-related hydrodolomite and the formation of oil and gas reservoirs in the Ordovician Trenton-Black River carbonate of Michigan, U.S.A., is described by Smith (2003). It may also be of interest to note that according to Eaton (2004), Hydro-Québec committed $330 million, in 2002, to an oil and gas exploration program in eastern Québec focused on hydrodolomite and faulting.

Acknowledgments

J. Young of the Department of Geological Sciences at the University of Manitoba is acknowledged for providing complimentary analytical support and digital copies of the results of drillcore analyses from stratigraphic coreholes drilled near the east end of PR 271. C. Lamb of Husky Energy Inc. is thanked for providing the results of the sample analyses from the Valley River northern outcrop. B. Lenton is gratefully acknowledged for preparing the figures in this report. M. Nicolas and R. Bezys provided many useful suggestions in their review of the manuscript.

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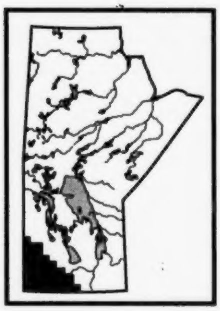


GS-17

Devonian Three Forks Formation, Manitoba (NTS 62F, parts of 62G, K): preliminary hydrocarbon and stratigraphic investigations

by M.P.B. Nicolas

Nicolas, M.P.B. 2007: Devonian Three Forks Formation, Manitoba (NTS 62F, parts of 62G, K): preliminary hydrocarbon and stratigraphic investigations; *in* Report of Activities 2007, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 175–185.

Summary

The Sinclair Field (Twp. 7–8, Rge. 28–29, W 1st Mer.) is the newest oilfield discovery in Manitoba and has greatly expanded in size and production since its discovery in 2004. The locality had been previously explored in the 1960s, but the pay was missed by early exploration efforts. Proven and probable reserves are estimated at 6.8 million m^3.

The Devonian Three Forks Formation is a cyclical transgressive-regressive sequence of shaly, silty dolarenite, interbedded with shale and brecciated in many places. The deposition of the Three Forks Formation was influenced by several weathering events due to transgressive and regressive cycles and basin tectonics. It is subdivided into four units, from bottom to top:

- Unit 1 is highly oxidized and is the lowermost and most widespread of the units; this unit is productive as a secondary reservoir in small isolated pools.
- Unit 2 is a sequence of interbedded siltstone and shale, massive shale and brecciated siltstone. The unit is productive as a secondary reservoir at the Sinclair and Daly fields (Twp. 9–10, Rge. 27–29, W 1st Mer.).
- Unit 3 is a thin, red-brown, highly oxidized silty shale.
- Unit 4, the uppermost unit represented in Manitoba, is an interbedded siltstone and silty shale with thick subunits of highly distorted and brecciated siltstone beds.

Unit 4 is the primary and most productive reservoir in the Sinclair Field. Units 2, 3 and 4 are productive at the unconformity surface as a subcrop-type play. In contrast, the production from Unit 1 is due to a stratigraphic-type play. The thinning of the Three Forks Formation and the truncation of the best reservoir units toward the east suggest the eastern expansion of the Sinclair Field may be limited. Mapping of these units toward the south along Rge. 29, W 1st Mer. indicates that Unit 4 is preserved up to the Manitoba–North Dakota international border, thereby extending the reservoir potential to the south.

The sub-Paleozoic extension of the Precambrian Superior Boundary Zone (SBZ) runs north-south in the study area. The Birdtail-Waskada Axis (BWA) runs roughly through the middle of the southern extent of the SBZ. Isopach, structural and geophysical evidence suggest the presence of faults running parallel to the SBZ eastern and western margins; these faults were active at the end of the Devonian. Movements along these faults caused the preservation of the primary reservoir (Unit 4) of the Three Forks Formation east and west of the SBZ margins, while the secondary reservoir unit (Unit 2) was exposed as a plateau on the BWA. The preservation of Unit 4 in some wells east of the BWA margin and along the SBZ margin opens up the possibility that, under the right trapping conditions, there may be another Sinclair-type play yet to be discovered east of Rge. 24, W 1st Mer.

Introduction

The study area consists of the entire depositional area of the Three Forks Formation in southwestern Manitoba (Figure GS-17-1).

The Sinclair Field is Manitoba's newest oilfield discovery. Since its discovery in 2004, it has been greatly expanded in size and production. The Sinclair Field has produced approximately 1.96 million m^3 of oil (cumulative to April 2007) and in 2006, represented 44% of Manitoba's total oil production. Proven and probable reserves are estimated at 6.8 million m^3 (J. Fox, pers. comm., 2007).

The productive interval of the Sinclair Field is dominantly the Devonian Three Forks Formation of the Qu'Appelle Group, with minor production from the overlying Middle Member of the Mississippian Bakken Formation (Figure GS-17-2). Minor production also comes from uphole, in the Lodgepole Formation.

The Three Forks Formation was influenced by transgressive and regressive cycles, periods of exposure, gravity flows (Karasinski, 2006) and basin tectonics.

Fifteen cores from the Sinclair Field and two cores from outside the field were logged as a first phase of this study (Nicolas, 2006). Geophysical logs for all wells that penetrated the Three Forks Formation (1355 wells in total) were viewed, and formational, member and unit tops were picked whenever possible in the Bakken, Three Forks and Birdbear formations. The final phase of this study will include logging Three Forks Formation cores from a more representative sampling of wells in the study area.

Geological setting

Southwestern Manitoba is situated along the northeastern flank of the Williston Basin. Strata from the Paleozoic, Mesozoic and Cenozoic form a basinward-thickening, southwesterly sloping wedge. The basin

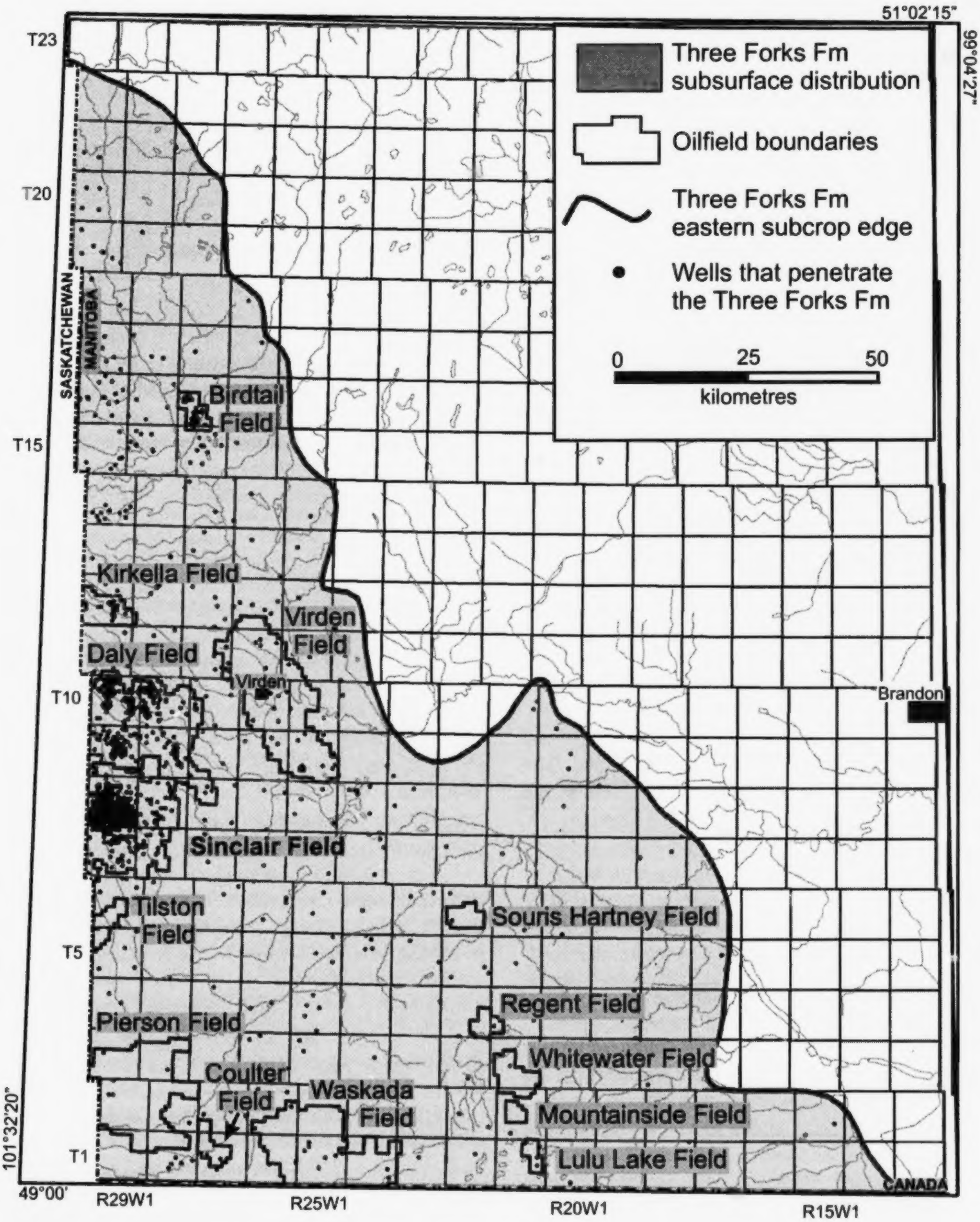

51°02'15"
99°04'27"
Three Forks Fm subsurface distribution
Oilfield boundaries
Three Forks Fm eastern subcrop edge
Wells that penetrate the Three Forks Fm
0
25
50
kilometres
T23
T20
T15
T10
T5
T1
SASKATCHEWAN
MANITOBA
Birdtail Field
Kirkella Field
Virden Field
Daly Field
Virden
Brandon
Sinclair Field
Tilston Field
Souris Hartney Field
Regent Field
Pierson Field
Whitewater Field
Coulter Field
Waskada Field
Mountainside Field
Lulu Lake Field
CANADA
101°32'20"
49°00'
R29W1
R25W1
R20W1
R15W1

Figure GS-17-1: *Map showing the study area and the Three Forks Formation subsurface distribution in southwestern Manitoba.*

reaches a total thickness of 2.3 km at its thickest point in the extreme southwestern corner of Manitoba, near the Saskatchewan interprovincial border and the North Dakota, United States international border.

Beneath the Phanerozoic cover in southwestern Manitoba is the southern extension of the Precambrian Superior Boundary Zone (SBZ), a major cratonic suture zone that runs north-south through the study area. The northern extent of the SBZ is host to world-class mineral deposits, but evidence of fluid movement and active faulting along this zone is not limited to the Precambrian: it extends into the Phanerozoic sedimentary cover. The Birdtail-Waskada Axis (BWA; McCabe, 1967; Dietrich et al., 1998; Dietrich et al., 1999) is a Devonian-

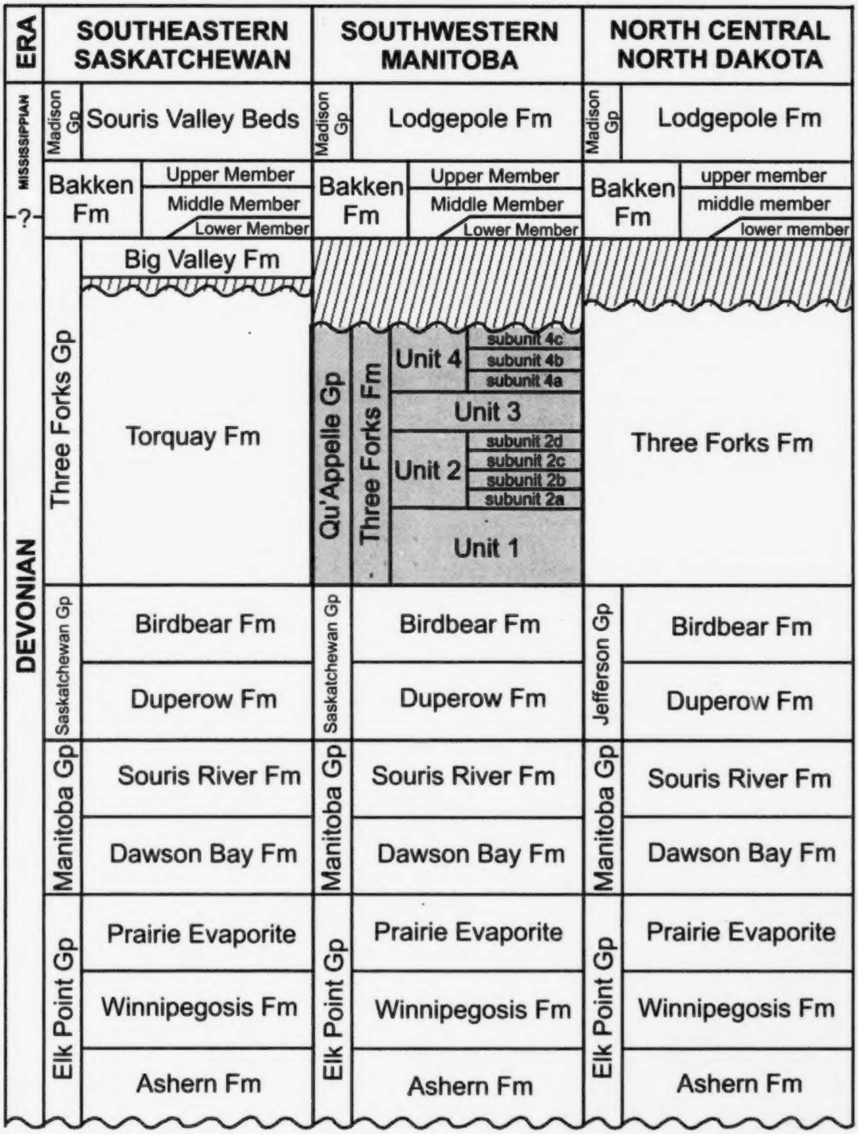

ERA
SOUTHEASTERN SASKATCHEWAN
SOUTHWESTERN MANITOBA
NORTH CENTRAL NORTH DAKOTA
MISSISSIPPIAN
Madison Gp
Souris Valley Beds
Lodgepole Fm
Lodgepole Fm
Bakken Fm
Upper Member
Middle Member
Lower Member
upper member
middle member
lower member
-?-
DEVONIAN
Big Valley Fm
Three Forks Gp
Torquay Fm
Qu'Appelle Gp
Three Forks Fm
Unit 4
subunit 4c
subunit 4b
subunit 4a
Unit 3
Unit 2
subunit 2d
subunit 2c
subunit 2b
subunit 2a
Unit 1
Three Forks Fm
Saskatchewan Gp
Jefferson Gp
Birdbear Fm
Duperow Fm
Manitoba Gp
Souris River Fm
Dawson Bay Fm
Elk Point Gp
Prairie Evaporite
Winnipegosis Fm
Ashern Fm

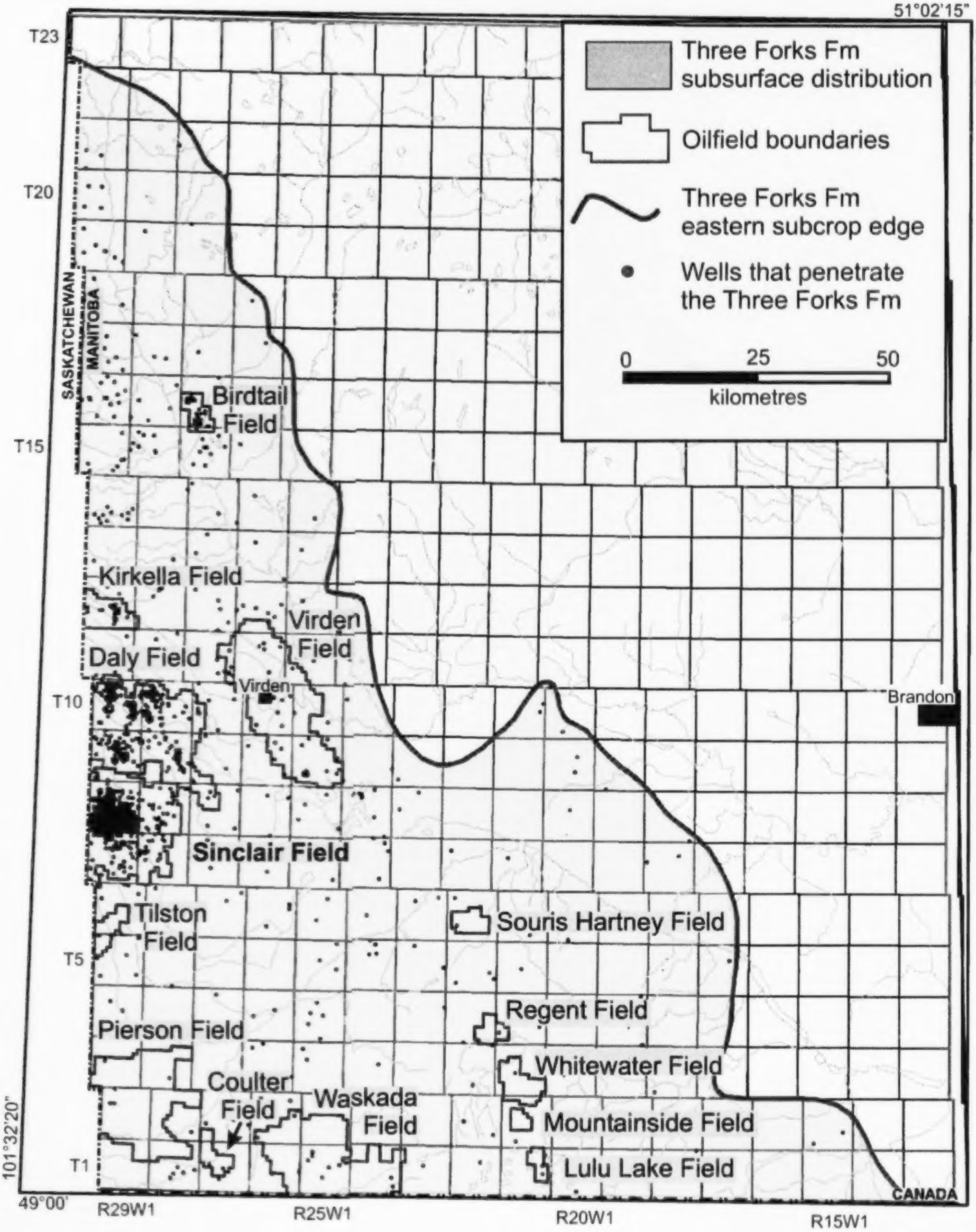
***Figure GS-17-2:** Stratigraphic correlations of the Mississippian and Devonian units in southwest Manitoba to neighbouring jurisdictions. Abbreviations: Fm, Formation; Gp, Group.*

Mississippian structure that runs roughly through the middle of the southern extent of the SBZ (Figure GS-17-3) and is the result of increased fluid movement through a basement-driven active fault and fracture system, causing the rapid dissolution of the Prairie Evaporite and subsequent collapse of the overlying strata.

The Paleozoic unconformity represents the largest time lapse in the history of the Phanerozoic, and is mostly due to tectonic uplift (McCabe, 1959). A progressive erosional truncation of the Paleozoic formations, from youngest in the west to oldest in the east, toward the basin margin, reflects the dynamic tectonic forces affecting the Williston Basin during this time. A widespread and significant erosional unconformity marking the end of the Devonian represents a period of uplift, which continued until the early Mississippian. The deposition, reworking and erosion of the Three Forks Formation were most affected by this event, in combination with salt dissolution effects from the dissolution of the underlying Prairie Evaporite.

Stratigraphy

The Three Forks Formation is a silty, shaly dolarenite stratigraphically positioned between the overlying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Three Forks Fm subsurface distribution
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Three Forks Fm eastern subcrop edge
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kilometres
T23
T20
T15
T10
T5
T1
SASKATCHEWAN
MANITOBA
Birdtail Field
Kirkella Field
Virden Field
Daly Field
Virden
Brandon
Sinclair Field
Tilston Field
Souris Hartney Field
Regent Field
Pierson Field
Whitewater Field
Coulter Field
Waskada Field
Mountainside Field
Lulu Lake Field
CANADA
101°32'20"
49°00'
R29W1
R25W1
R20W1
R15W1

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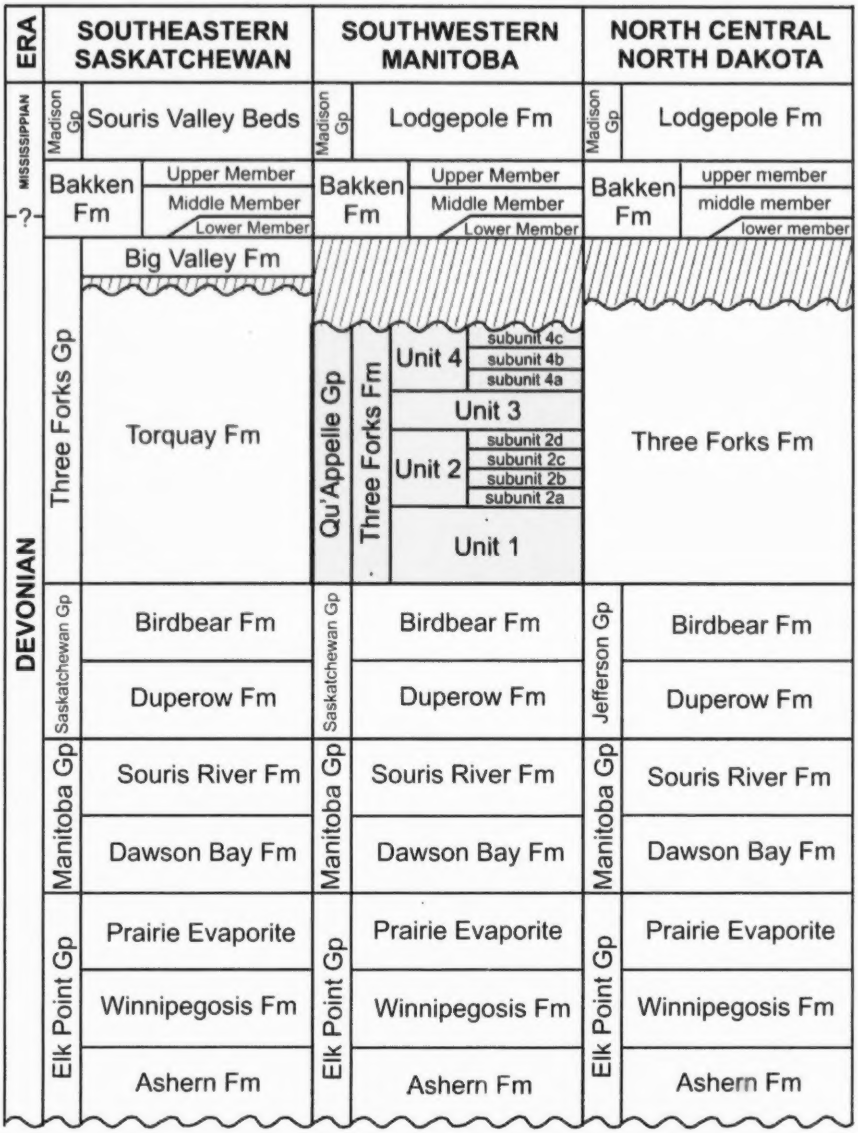
ERA
SOUTHEASTERN SASKATCHEWAN
SOUTHWESTERN MANITOBA
NORTH CENTRAL NORTH DAKOTA
MISSISSIPPIAN
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Lodgepole Fm
Madison Gp
Lodgepole Fm
Bakken Fm
Upper Member
Middle Member
Lower Member
Bakken Fm
Upper Member
Middle Member
Lower Member
Bakken Fm
upper member
middle member
lower member
Three Forks Gp
Big Valley Fm
Torquay Fm
Qu'Appelle Gp
Three Forks Fm
Unit 4
subunit 4c
subunit 4b
subunit 4a
Unit 3
Unit 2
subunit 2d
subunit 2c
subunit 2b
subunit 2a
Unit 1
Three Forks Fm
Saskatchewan Gp
Birdbear Fm
Duperow Fm
Saskatchewan Gp
Birdbear Fm
Duperow Fm
Jefferson Gp
Birdbear Fm
Duperow Fm
Manitoba Gp
Souris River Fm
Dawson Bay Fm
Manitoba Gp
Souris River Fm
Dawson Bay Fm
Manitoba Gp
Souris River Fm
Dawson Bay Fm
Elk Point Gp
Prairie Evaporite
Winnipegosis Fm
Ashern Fm
Elk Point Gp
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Prairie Evaporite
Winnipegosis Fm
Ashern Fm

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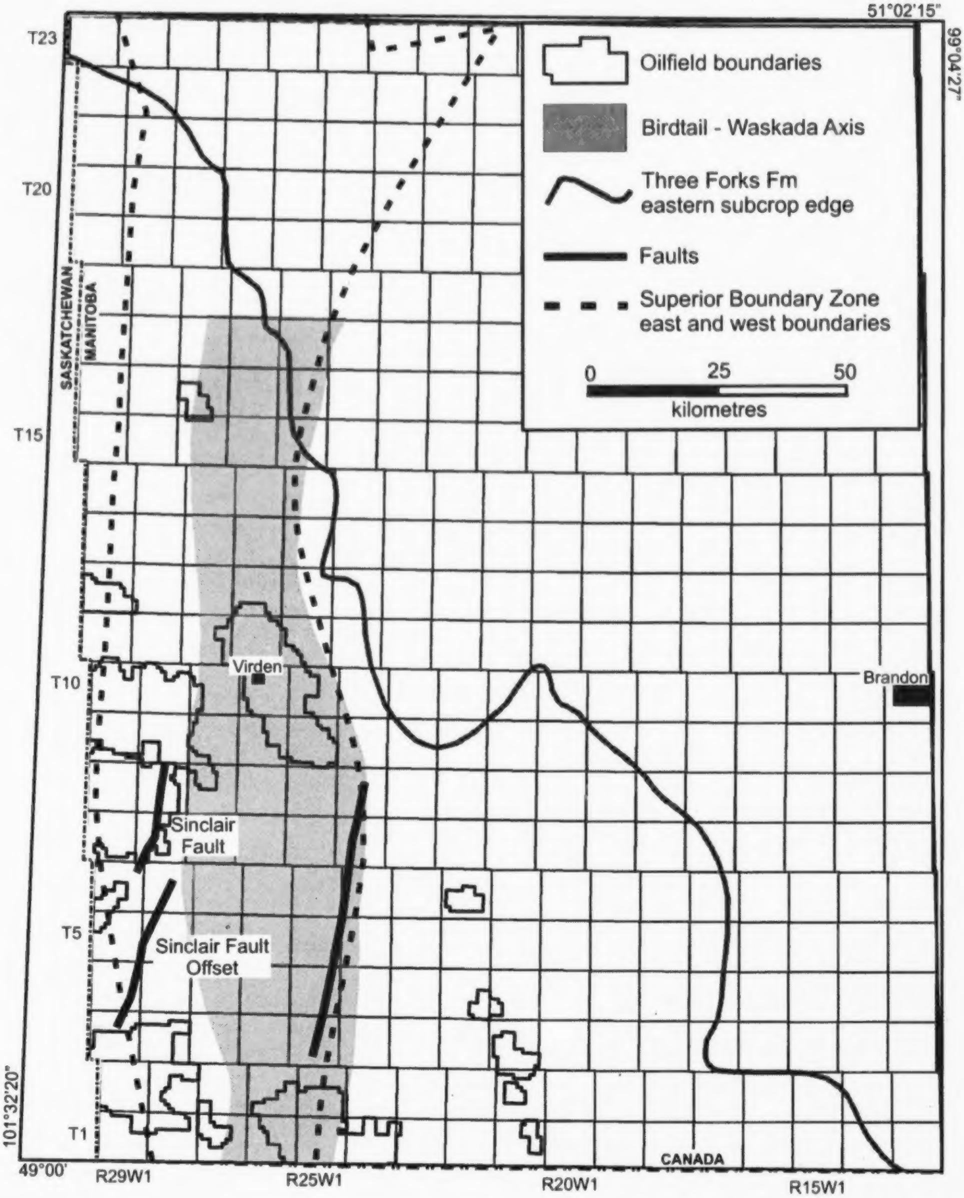
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Oilfield boundaries
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Three Forks Fm eastern subcrop edge
Faults
Superior Boundary Zone east and west boundaries
0
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kilometres
T23
T20
T15
T10
T5
T1
SASKATCHEWAN
MANITOBA
Virden
Brandon
Sinclair Fault
Sinclair Fault Offset
CANADA
101°32'20"
49°00'
R29W1
R25W1
R20W1
R15W1

Figure GS-17-3: *Simplified tectonic map of the study area showing the Superior Boundary Zone (SBZ), the Birdtail-Waskada Axis (BWA) and fault lines.*

siltstone, sandstone and shale layers of the Mississippian Bakken Formation, and underlying carbonate and evaporite layers of the Devonian Birdbear Formation, Saskatchewan Group (Figure GS-17-2). The Three Forks Formation is subdivided into four units (described below); similar to those recognized in southeastern Saskatchewan by Christopher (1961). In this study, Units 2 and 4 are further subdivided into subunits (Figure GS-17-4). Figure GS-17-4 shows a reference log for the Three Forks Formation.

Unit 1

Unit 1 is the lowermost unit of the Three Forks Formation (Figure GS-17-2) and is present uniformly up to the subcrop edge (Figure GS-17-5a). This unit is the least understood of all four units due to its limited core availability. It has a fairly constant isopach, averaging 16 m. It is highly oxidized with occasional grey-green reduction haloes. The original fabric may have been a brecciated argillaceous dolomite with grey-green silty shale matrix. Unit 1 is productive within two small

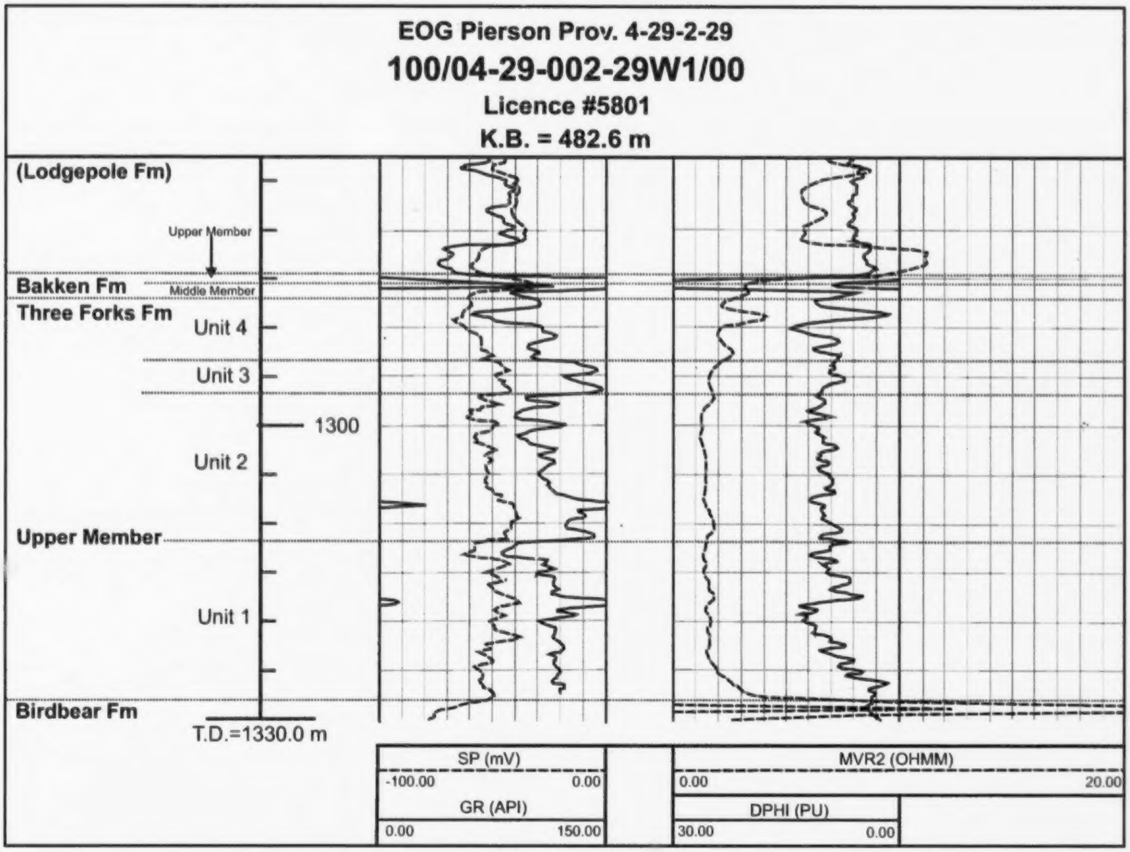

Figure GS-17-4: *Three Forks Formation reference log of the 04-29-002-29W1 well.*

isolated pools in the Sinclair Field. Its future reservoir potential is unknown, but looks promising.

Unit 2

Unit 2, shown in Figure GS-17-2, is a sequence of interbedded siltstone and shale, massive shale and brecciated siltstone that have been partially oxidized. Unit 2 is subdivided into four subunits; from bottom to top they are named subunits 2a, 2b, 2c and 2d. The isopach for this unit averages 15 m, reaching a maximum thickness of 19 m in the Sinclair area to less than 1 m as the distribution limit in the east is approached (Figure GS-17-5b). The distribution limit for Unit 2 roughly follows the eastern boundary of the BWA and the SBZ. With porosity decreasing with depth, its best reservoir locations are where the upper half of the unit is exposed at the unconformity surface. It is productive as a secondary reservoir in the Sinclair Field, where production from this unit is 1) only economical when commingled with a better producing zone uphole, or 2) the oil production is economically borderline compared to other wells in the field. In the Daly and Kirkella fields (Twp. 9–12, Rge. 27–29, W 1st Mer.), Unit 2 is a primary reservoir when its production is commingled with that of the Middle Member of the Bakken Formation.

Unit 3

Unit 3 (Figure GS-17-2) is a red-brown, highly oxidized, tight silty dolomitic shale with rare grey-green reduction haloes. Its distribution follows Unit 4 closely, and is present in isolated wells east of its main subcrop edge (Figure GS-17-5c). It is easy to see on logs with its consistent log signature (Figure GS-17-4) and uniform isopach, averaging 3.5 m. While this unit is tight, it can be productive when perforated in conjunction with Unit 2 (when Unit 3 occurs at the Devonian unconformity surface).

Unit 4

Unit 4, depicted in Figure GS-17-2, is the uppermost unit represented in the Three Forks Formation in Manitoba, and is an interbedded siltstone, with argillaceous dolomite and silty dolomitic shale of highly distorted and brecciated dolomitic siltstone beds. Unit 4 is subdivided into three subunits; from bottom to top they are named subunits 4a, 4b and 4c. Its isopach ranges from 1 to 14 m, but more commonly averages 6 m. This unit has a limited

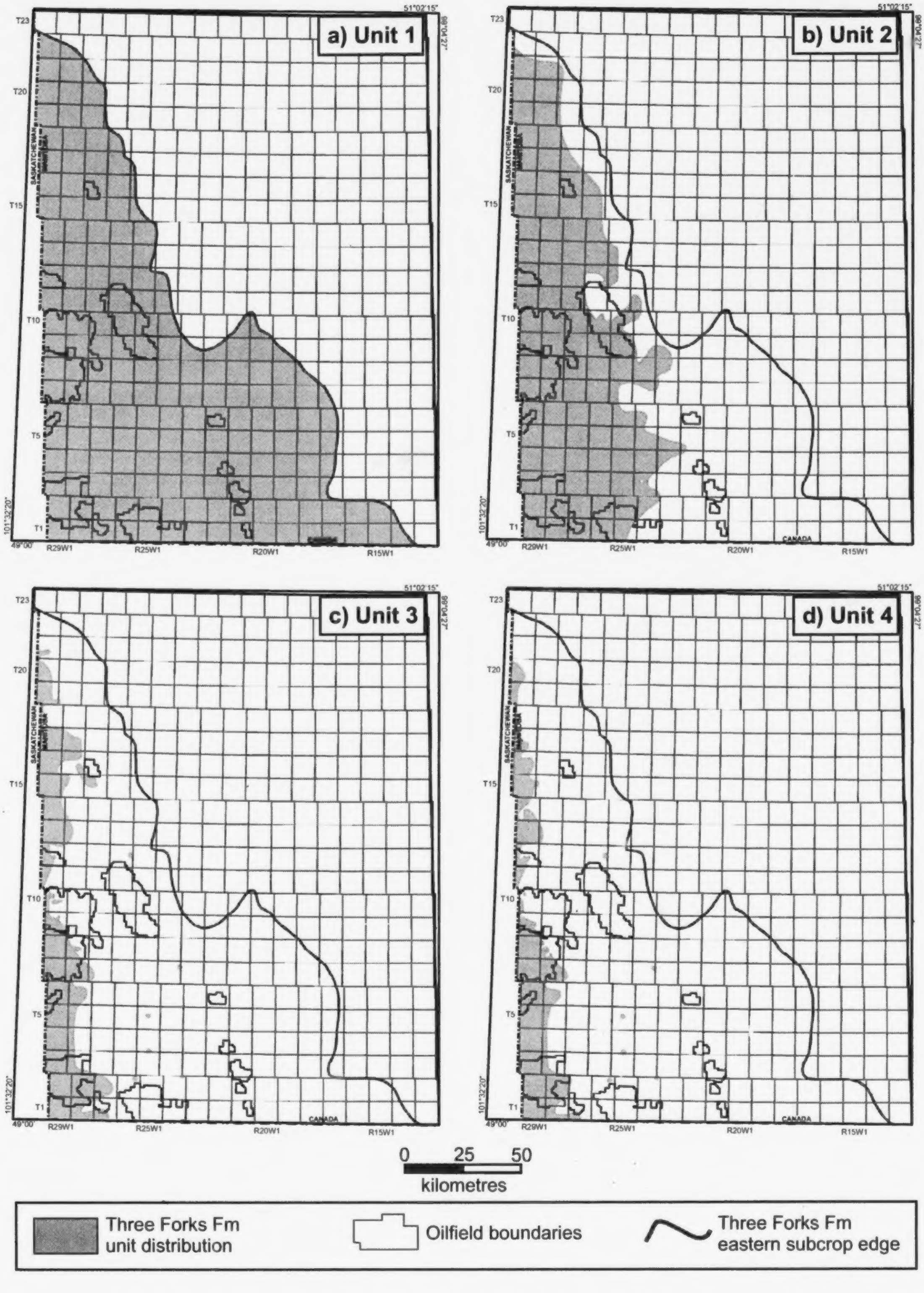
a) Unit 1
b) Unit 2
c) Unit 3
d) Unit 4
T23
T20
T15
T10
T5
T1
R29W1
R25W1
R20W1
R15W1
51°02'15"
98°04'27"
101°32'20"
49°00'
SASKATCHEWAN
MANITOBA
CANADA
0
25
50
kilometres
Three Forks Fm unit distribution
Oilfield boundaries
Three Forks Fm eastern subcrop edge

***Figure GS-17-5:** Distribution map and subcrop edge for each unit in the Three Forks Formation, Manitoba: **a)** Unit 1 distribution; **b)** Unit 2 distribution; **c)** Unit 3 distribution and **d)** Unit 4 distribution. Abbreviation: Fm, Formation.*

distribution in Manitoba, being restricted to Rge. 28–29, W 1st Mer., and westward into Saskatchewan; like Unit 3, it is preserved in isolated wells east of its main subcrop edge (Figure GS-17-5d). Unit 4 production is commingled with the Middle Member of the Bakken Formation, and together they comprise the primary and most productive reservoir in the Sinclair Field. In addition, the combined interval forms a small isolated pool in Twp. 4, Rge. 29, W 1st Mer. (abbreviated 4-29-W1). It should also be noted that production also originates from subunits 4b and 4c, whichever is present at the unconformity surface. Minor production from Unit 4 is present in the southern sections of the Daly Field and one well in the Kirkella Field (Figure GS-17-1, -5d). At the Sinclair Field, the average core permeability is 4.3 mD, and average core porosity is 16.5%.

Deposition and diagenesis

The Three Forks Formation is a cyclical transgressive-regressive sequence of argillaceous dolomite, brecciated, interbedded and interlaminated with silty dolomitic shale and claystone. This formation was influenced by transgressive and regressive cycles, periods of exposure, gravity flows (Karasinski, 2006) and basin tectonics. According to Karasinski (2006), the Three Forks Formation was deposited along a temperate, carbonate tidal flat that grades basinward toward an unrimmed carbonate platform. Karasinski's report is based on an area six townships in size, centred on the Sinclair Field. The final phase of the Three Forks Formation study will attempt to verify Karasinski's model on a larger scale; and if necessary, a more appropriate depositional model will be developed.

Karasinski (2006) noted that several stages of diagenesis have occurred with dolomitization of the entire sequence occurring at early and middle stages of diagenesis. He also reported that porosity development and occlusion developed as early- and late-stage diagenetic alterations.

Isopach and structure

The regional isopach of the Three Forks Formation generally thickens east to west, with its greatest thickness observed from 8-29-W1 south to the international border with the United States (Figure GS-17-6). The trend of the isopach contours parallels the SBZ and BWA margins. The formation thins eastward with a rapid successive truncation of the units of the Three Forks Formation toward the east. The units are truncated at the pre-Mississippian erosional surface. Units 3 and 4 are sharply truncated along a north-south trend between Rge. 28 and 29, W 1st Mer. East of this truncation, the isopach gradually thins eastward toward the subcrop edge, east of Rge. 25, W 1st Mer. Anomalously thick sections occur in a few wells far to the east, in Rge. 24 and 25, W 1st Mer., where Units 3 and 4 are preserved. Anomalous thicknesses of the Three Forks Formation are also noted in wells located at the Virden Field to the northeast (Figure GS-17-6).

The structure of the Three Forks Formation shows a general southeast trend, with synclinal flexures in the structure contours visible at the Sinclair, Daly and Virden fields (Figure GS-17-7). Pronounced structural highs occur in the Daly Field, mimicking those seen in the Mississippian (Klassen, 1996). A prominent synclinal flexure of the contours is seen in the western half of 8-28-W1.

Tectonics

The sub-Paleozoic extension of the Precambrian SBZ runs north-south in this area. The BWA runs roughly through the middle of the southern extension of the SBZ (Figure GS-17-3). Isopach and structural evidence suggest the presence of faults running parallel to the SBZ eastern and western margins (Nicolas, 2006); these faults were active at the end of the Devonian. The western faults are referred to as the Sinclair Fault and Sinclair Fault Offset (Nicolas, 2006), the latter being an en échelon extension of the former (Figure GS-17-3). Block faulting along this zone caused the preservation of the primary reservoir (Unit 4) of the Three Forks Formation east and west of the SBZ margins, while the secondary reservoir unit (Unit 2) was exposed as a plateau on the BWA. The preservation of Unit 4 in some wells east of the SBZ margin opens up the possibility that, under the right trapping conditions, there may be another Sinclair-type play yet to be discovered east of Rge. 24, W 1st Mer.

To support this faulting theory, Dietrich et al. (1998, 1999) identified several faults using seismic data along a transect from southeastern Saskatchewan to southwestern Manitoba, one of which coincides precisely with the subcrop edge of Unit 4, which is truncated in Rge. 28, W 1st Mer. This same transect identified a fault running roughly north-south around Rge. 25, W 1st Mer., which may explain the preservation of Unit 4 near the eastern limit of the SBZ. The margin of a well-defined magnetic and gravity anomaly (Viljoen et al., 1999) also coincides with the location of the eastern fault shown in Figure GS-17-3.

Conclusions

Up to this point, exploration of the Three Forks Formation has been combined with the Bakken Formation exploration in Manitoba. The two formations are often considered a continuous, commingled reservoir with no hydrological barrier between them, and are therefore pooled together. The Three Forks Formation is currently productive in the Sinclair, Daly and Kirkella fields and 4-29-W1. It is a new exploration target, and has to be explored in detail in other areas of the province.

The uppermost of the Three Forks Formation units, Unit 4, is the primary and most productive reservoir at the Sinclair Field and in the small pool in 4-29-W1 (Figure GS-17-1). Production is also derived from Unit

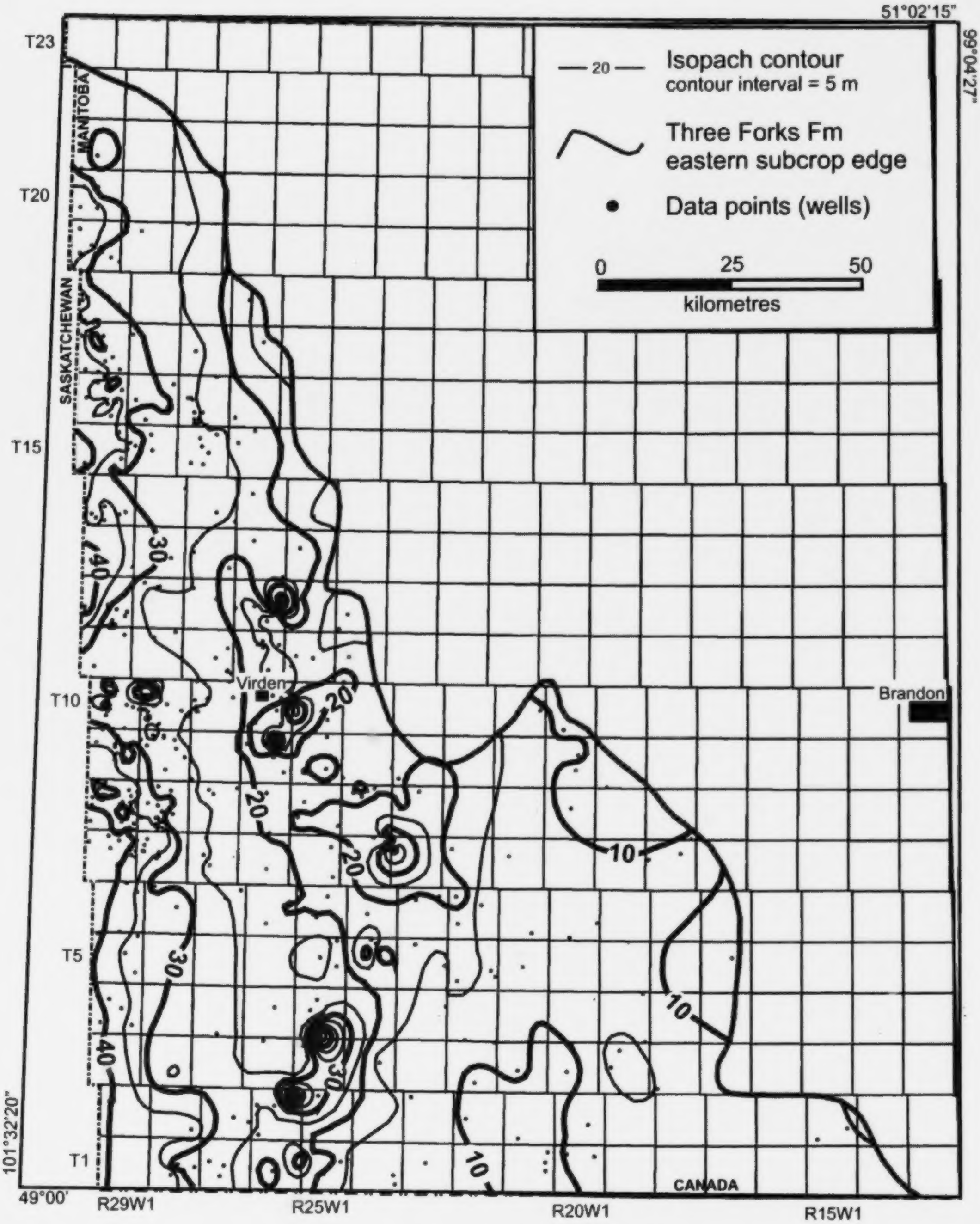
51°02'15"
99°04'27"
T23
T20
T15
T10
T5
T1
101°32'20"
49°00'
R29W1
R25W1
R20W1
R15W1
MANITOBA
SASKATCHEWAN
Virden
Brandon
CANADA
30
40
20
10
20 Isopach contour
contour interval = 5 m
Three Forks Fm eastern subcrop edge
Data points (wells)
0
25
50
kilometres

Figure GS-17-6: *Isopach of the Devonian Three Forks Formation; contour interval is 5 m.*

2, a secondary reservoir in the Sinclair, Daly and Kirkella fields. The thinning of the Three Forks Formation and the truncation of Unit 4 eastward suggests that the eastern expansion of the Sinclair Field may be limited. In contrast, the thick isopach trend running north-south along Rge. 29, W 1st Mer., where Unit 4 is still present, suggests a southern expansion of the Sinclair Field and northern expansion of the Daly and Kirkella fields may also be successful. It should be noted that much of 4-29-W1 remains unexplored.

Isopach and structural evidence suggests block faulting may have occurred in the western sections of

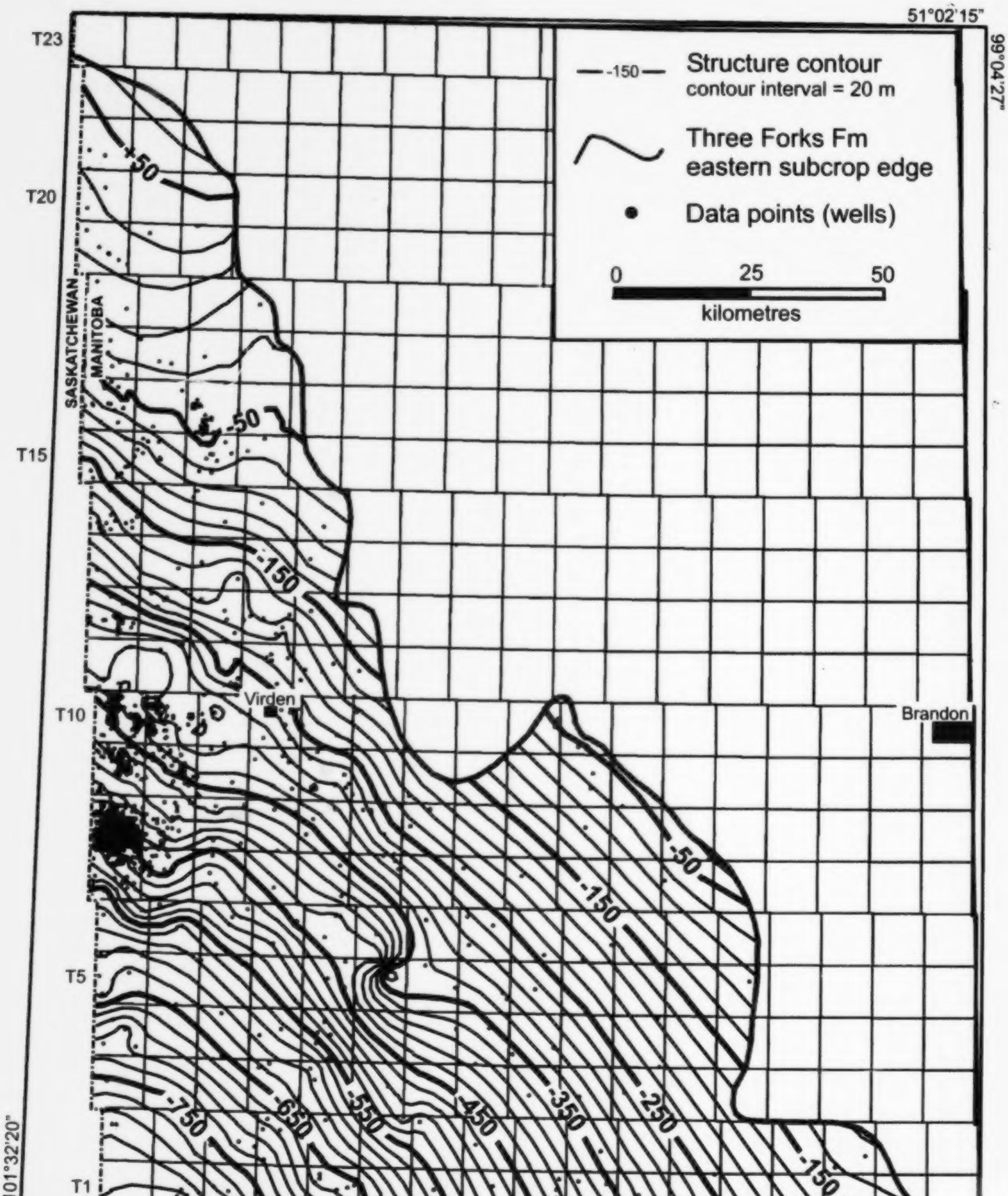
51°02'15"
99°04'27"
-150 Structure contour
contour interval = 20 m
Three Forks Fm eastern subcrop edge
● Data points (wells)
0
25
50
kilometres
T23
T20
T15
T10
T5
T1
SASKATCHEWAN
MANITOBA
+50
-50
-150
-50
-150
-750
-650
-550
-450
-350
-250
-150
Virden
Brandon
CANADA
101°32'20"
49°00'
R29W1
R25W1
R20W1
R15W1

Figure GS-17-7: Structure contours of the Devonian Three Forks Formation; contour interval is 20 m.

Rge. 28, W 1st Mer., south of Twp. 9. This faulting would have resulted in uplift and the subsequent erosional truncation of Units 3 and 4 along eastern limits of Rge. 28, W 1st Mer. The fault trend may serve as a geological boundary in determining the eastern boundary of the Sinclair Field. The identification of a fault on the eastern edge of the BWA along Rge. 24 and 25, W 1st Mer. (Figure GS-17-3), coinciding with wells having preserved sections of Units 3 and 4, may provide a similar reservoir in the west.

Economic considerations

The Devonian Three Forks Formation of the Qu'Appelle Group in southwestern Manitoba has tremendous hydrocarbon exploration potential. Future development of known oil pools exists potentially along the north-south trend of Unit 4. Unit 2 has its best development potential in areas where subunit 2b is present and where subunit 2c has been minimally affected by oxidation.

New exploration efforts should be targeted north and east of the Sinclair Field within Unit 2, and possibly Unit 1. The fact that Unit 1 is productive in a small pool in the Sinclair Field suggests that more potential exists in this unit in all areas where the Three Forks Formation is present. Log signatures of Unit 1 look promising west of the Unit 2 subcrop edge, but core of this unit is not available to correlate with the log signatures. Possible target zones may occur along the north-south trend parallel to the eastern limit of the SBZ, from Rge. 24 to 25, W 1st Mer., where local occurrences of Unit 4 have been preserved, based on log correlations. It is possible that another Sinclair Field is yet to be discovered along this eastern trend. Figure GS-17-8 summarizes the most promising Three Forks Formation exploration target areas.

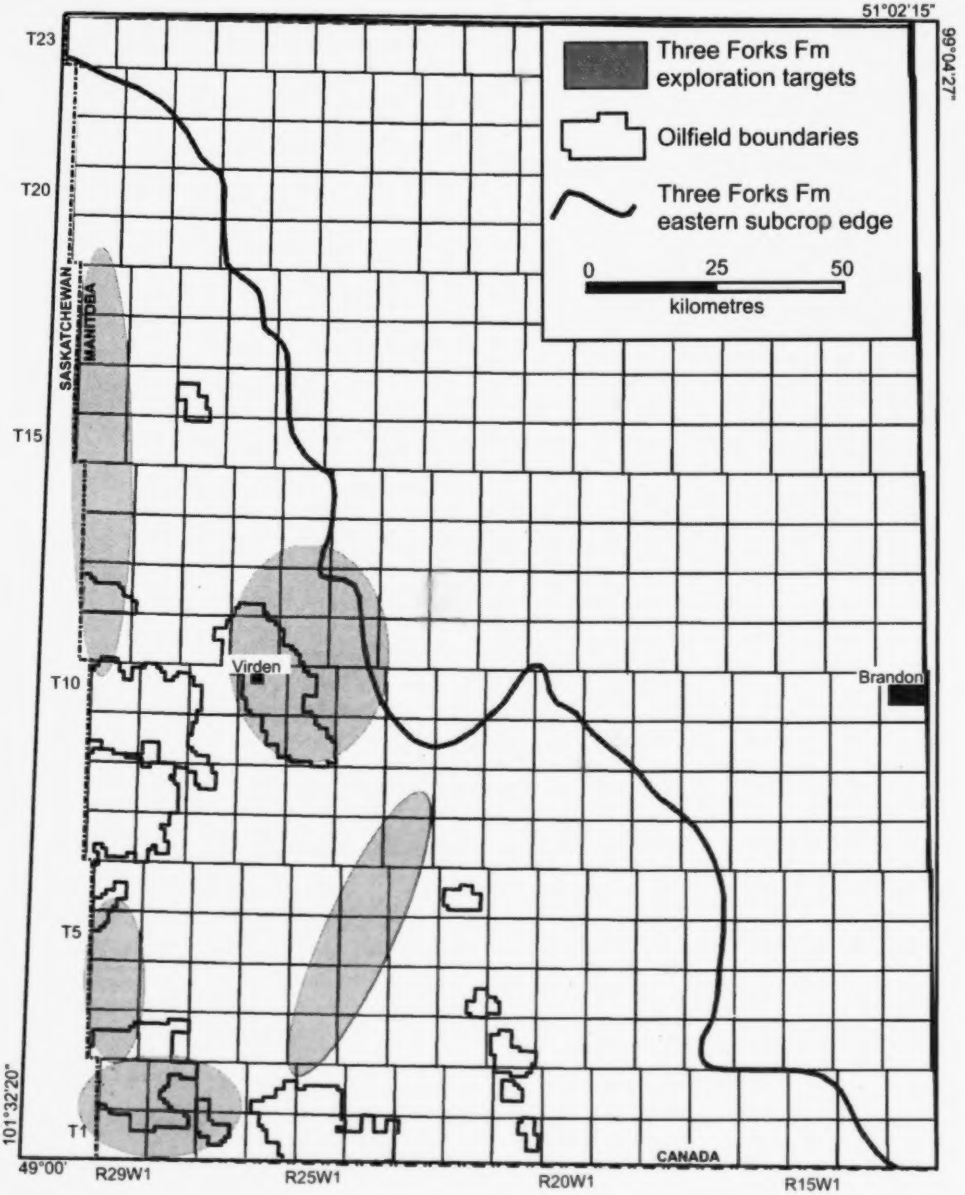
51°02'15"
99°04'27"
T23
T20
T15
T10
T5
T1
101°32'20"
49°00'
R29W1
R25W1
R20W1
R15W1
SASKATCHEWAN
MANITOBA
Virden
Brandon
CANADA
Three Forks Fm exploration targets
Oilfield boundaries
Three Forks Fm eastern subcrop edge
0
25
50
kilometres

Figure GS-17-8: Devonian Three Forks Formation recommended exploration target areas.

Acknowledgments

The author would like to thank J. Fox (Mineral Resources Division, Manitoba Science, Technology, Energy and Mines) for his Sinclair Field reserves estimates.

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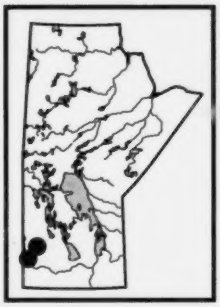
GS-18 Industrial mineral potential of the rural municipalities of Miniota, Archie and Rossburn, Manitoba (parts of NTS 62K)

by J.D. Bamburak

Bamburak, J.D. 2007: Industrial mineral potential of the rural municipalities of Miniota, Archie and Rossburn, Manitoba (parts of NTS 62K); *in* Report of Activities 2007, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 186–194.



Summary

The rural municipalities of Miniota, Archie and Rossburn contain the following undeveloped industrial minerals that could be used for the economic benefit of local residents, and to the province as a whole:

- Souris-type gravel (Rural Municipality [R.M.] of Miniota)
- swelling sodium bentonite (R.M. of Miniota)
- potash and sodium chlorate (R.M. of Archie)
- manganese (R.M. of Rossburn)

Souris-type gravel is present in the Assiniboine River valley, south of the community of Miniota. The gravel contains exotic boulders and cobbles similar to those found at Souris, which are prized by rockhounds who are willing to pay to collect the specimens. Swelling sodium bentonite is present, near surface, to the north (near Beulah) and south (Hawley dugout) of the community of Miniota. The major use of the bentonite is as a drilling mud, but can also be used for other products, such as kitty litter or to produce an impervious liner that can be used at the base of fish ponds and landfill sites. Potash is used in the production of fertilizer in Saskatchewan, where mining is done on a major scale. A geological estimate of 170 million tonnes grading 20% K_2O in sylvite, has been indicated in the northern portion of the R.M. of Archie, south of two other proven deposits situated between the towns of McAuley and Russell. The potential for a potash mine in southwest Manitoba is great, depending on commodity prices. Sodium chlorate used in the paper industry can be produced as a value-added product from sodium chloride, which is a byproduct of potash production. Currently, sodium chlorate is produced in Brandon from sodium chloride imported from Saskatchewan potash producers. Manganese is a major steel alloying constituent and is also used in a variety of nonmetallurgical uses, including battery, tile, ceramic and glass production and water treatment. Small quantities of chemical grade manganese may be recoverable in the vicinity of Birdtail Creek in the R.M. of Miniota.

Introduction

At the request of T. Charney (Economic Development Officer for the rural municipalities of Miniota, Archie and Rossburn), a presentation on the industrial mineral potential of the rural municipalities of Miniota and Archie (Figure GS-18-1) was given in the community of Miniota in September 2006. This was followed in June 2007, with a talk on the industrial mineral potential of the R.M. of Rossburn (Figure GS-18-1) in the town of Rossburn; and a repeat presentation of the industrial mineral potential of the rural municipalities of Miniota and Archie in the community of Miniota.

Industrial mineral commodities presented in the talks included Souris-type gravel, swelling sodium bentonite, potash, sodium chlorate and manganese, all of which have been documented in the literature for Manitoba. During the preparation of the 2006 and 2007 talks, it was realized that the visits to these municipalities would also afford opportunities to field check new and known industrial mineral sites, and to update the files of the Manitoba Geological Survey. As a result, brief reconnaissance field investigations were carried out on most of the following industrial mineral commodities.

Souris-type gravel (R.M. of Miniota)

Pleistocene gravel deposits containing clasts of western (Rocky Mountain) provenance mixed with more common glacial pebble types derived from Manitoba bedrock (Precambrian granite and gneiss and Phanerozoic carbonate and shale) are present in southwest Manitoba. Klassen (1969, 1979) informally named these deposits "Souris gravel and sand" after a mixture found in an aggregate pit located in SW¼, L.S. 9, Sec. 34, Twp. 7, Rge. 21, W 1st Mer. (abbreviated SW-9-34-7-21-W1), near Souris (Figure GS-18-1). He also identified five other localities (from an excavation and boreholes situated within Twp. 4–23, Rge. 20–29, W 1st Mer.), where Souris-type gravel deposits are present, at depth, beneath substantial overburden.

In September 2006, R. Rowan, a resident of the R.M. of Miniota, showed that Souris-type gravel is present in the Armitage gravel pit (Figure GS-18-2). The pit is located in the Assiniboine River valley, 3 km southeast of the community of Miniota, in NE-18-13-26-W1 and SE-19-13-26-W1. The gravel comprises about 25% exotic sub- to well-rounded cobbles and boulders (including septarium and other concretions, quartzite, petrified wood, porphyritic volcanic rock, chert and jasper) mixed with about 75% typical glacial gravel. For the most part, these cobbles and boulders appear to have the same western provenance as those found at Souris; and therefore, the deposit can be considered to be Souris-type. However, compared with the Souris pit, the Armitage pit contains numerous large, rigid, and

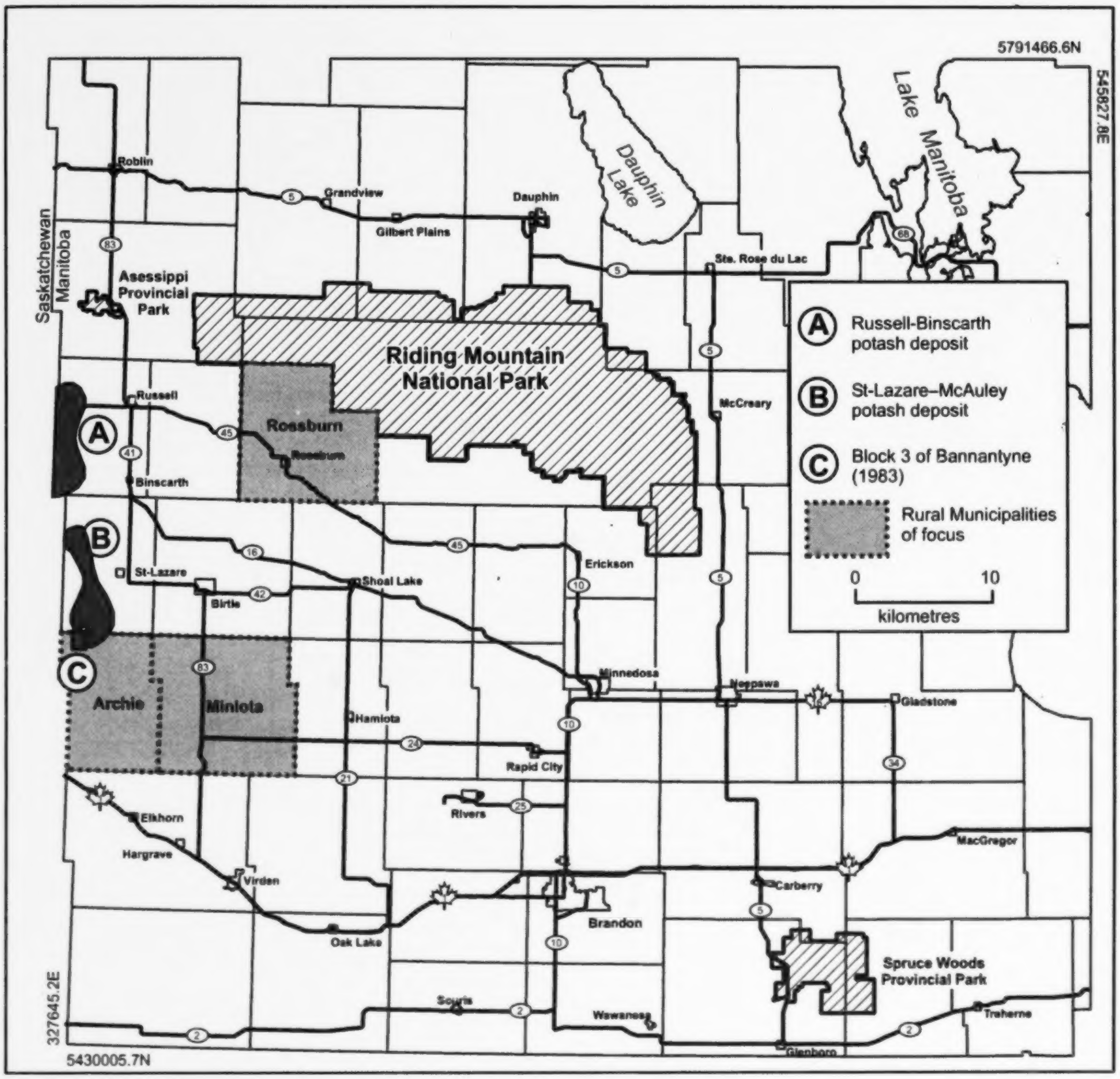

5791466.6N
545827.8E
327645.2E
5430005.7N
Saskatchewan
Manitoba
Lake Manitoba
Dauphin Lake
Roblin
Grandview
Gilbert Plains
Dauphin
Ste. Rose du Lac
Asessippi Provincial Park
Riding Mountain National Park
Russell
Rossburn
Binscarth
McCreary
St-Lazare
Birtle
Shoal Lake
Erickson
Archie
Miniota
Hamiota
Minnedosa
Neepawa
Gladstone
Rapid City
Elkhorn
Hargrave
Virden
Rivers
MacGregor
Carberry
Oak Lake
Brandon
Spruce Woods Provincial Park
Souris
Wawanesa
Treherne
Glenboro
A
B
C
5
83
45
41
16
42
10
24
21
25
34
68
2
Russell-Binscarth potash deposit
St-Lazare–McAuley potash deposit
Block 3 of Bannantyne (1983)
Rural Municipalities of focus
0
10
kilometres

***Figure GS-18-1:** Locations of the rural municipalities of Miniota, Archie and Rossburn in southwest Manitoba. Also shown are the Russell-Binscarth and St-Lazare–McAuley potash deposits and Block 3 of Bannatyne (1983).*

sometimes fossiliferous, septarium and other types of concretions (Figure GS-18-3), which appear to have a local provenance within the Cretaceous Pierre Shale.

The cobbles and boulders found at the Souris pit are prized by rockhounds, who collect specimens from the pit after purchasing a permit from Souris River Gem Ltd. at their store (The Rock Shop) in Souris. Many of the specimens are cut and polished to make ornaments and jewellery. With the identification of Souris-type gravel in the Miniota area, there is an opportunity to develop a similar local rockhound collecting site. The sand and gravel rights for aggregate in the Armitage pit are partially held privately and under quarry lease by the R.M. of Miniota from the Crown. An area with good potential for the discovery of additional Souris-type gravel surrounds the Armitage gravel pit (Figure GS-18-2). Several other gravel pits in the R.M. of Miniota contain similar exotic clasts to those found in the Armitage pit and these will be documented in the future.

Swelling sodium bentonite (R.M. of Miniota)

The major use of swelling sodium bentonite is as a drilling mud for the petroleum industry. The bentonite can also be used for a variety of other products, such as kitty litter or an impervious liner that can be used at the base of fish ponds and landfill sites.

Beulah outcrop

In 1967, a bentonite sample with good swelling properties was submitted to the Manitoba Mines Branch

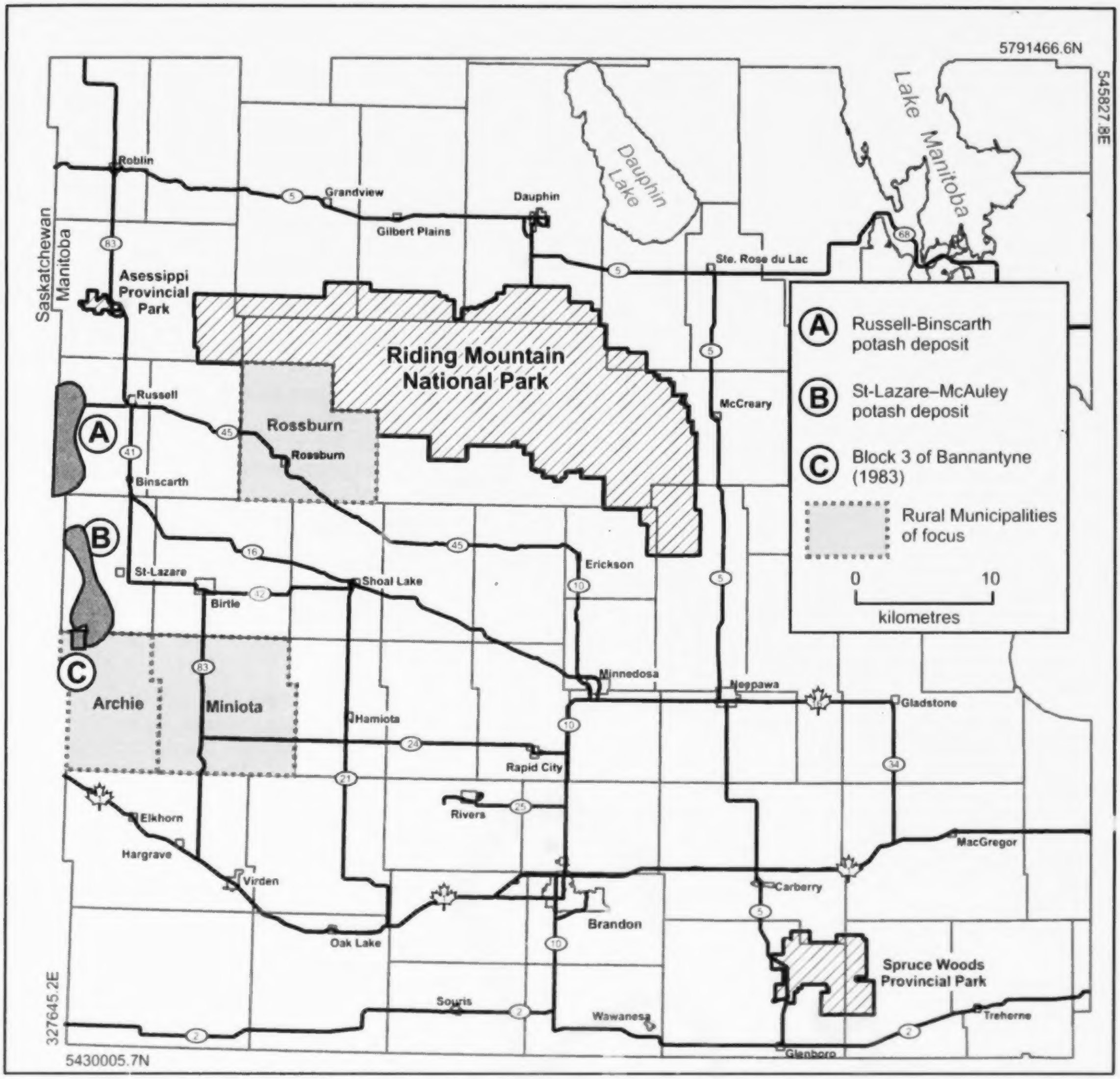

5791466.6N
545827.8E
Lake Manitoba
Dauphin Lake
Roblin
Grandview
Dauphin
Gilbert Plains
Saskatchewan
Manitoba
Asessippi Provincial Park
Ste. Rose du Lac
Riding Mountain National Park
Russell
Rossburn
Rossburn
Binscarth
St-Lazare
Birtle
Shoal Lake
Erickson
McCreary
Minnedosa
Neepawa
Gladstone
Archie
Miniota
Hamiota
Rapid City
Rivers
Elkhorn
Hargrave
Virden
Oak Lake
Brandon
Carberry
MacGregor
Spruce Woods Provincial Park
Souris
Wawanesa
Treherne
Glenboro
327645.2E
5430005.7N
A Russell-Binscarth potash deposit
B St-Lazare–McAuley potash deposit
C Block 3 of Bannantyne (1983)
Rural Municipalities of focus
0
10
kilometres

Figure GS-18-1: Locations of the rural municipalities of Miniota, Archie and Rossburn in southwest Manitoba. Also shown are the Russell-Binscarth and St-Lazare–McAuley potash deposits and Block 3 of Bannatyne (1983).

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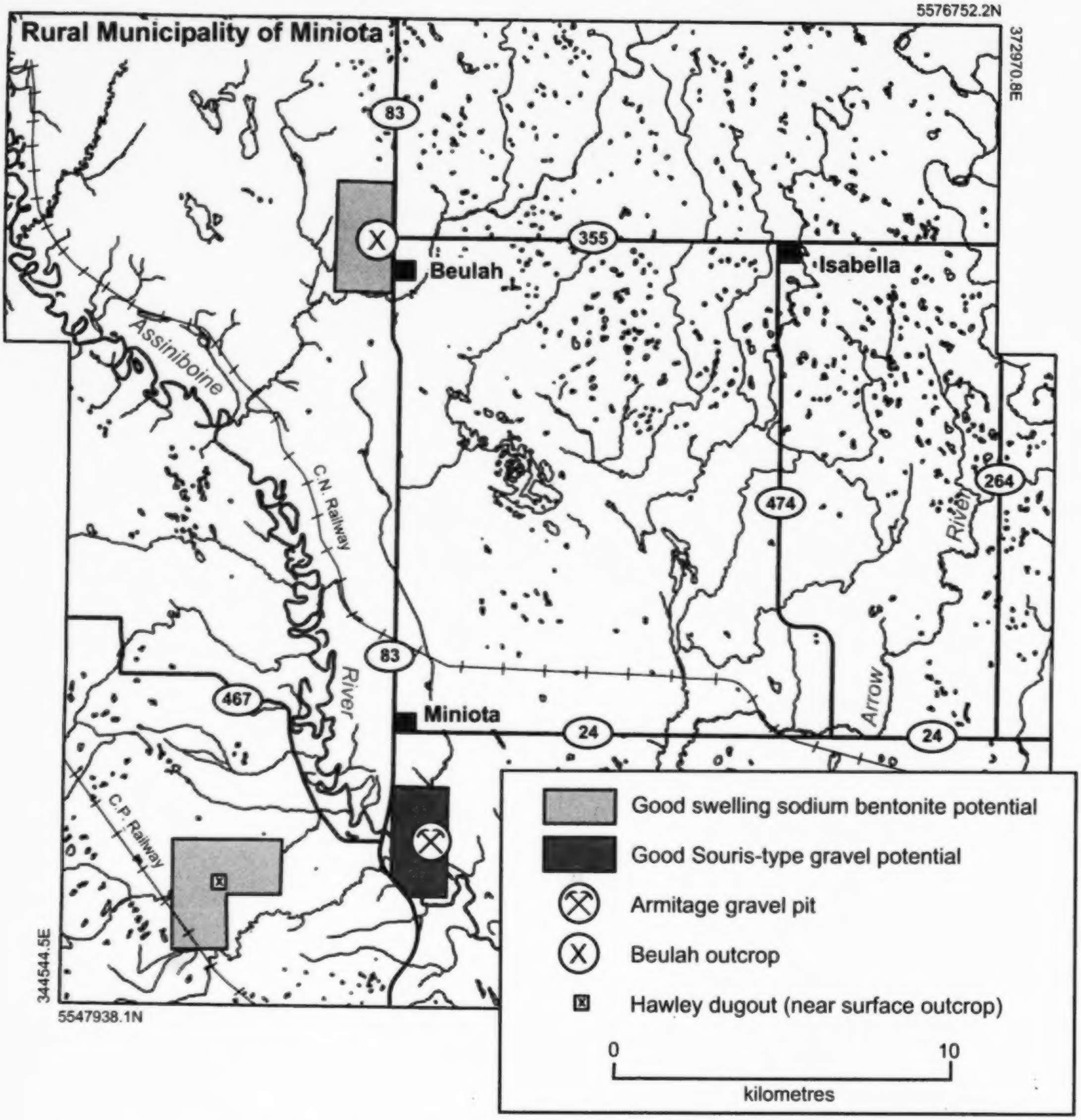
Rural Municipality of Miniota
5576752.2N
372970.8E
83
355
Beulah
Isabella
Assiniboine
C.N. Railway
474
264
River
83
River
467
Miniota
24
Arrow
24
C.P. Railway
344544.5E
5547938.1N
Good swelling sodium bentonite potential
Good Souris-type gravel potential
Armitage gravel pit
Beulah outcrop
Hawley dugout (near surface outcrop)
0
10
kilometres

***Figure GS-18-2:** Areas within the Rural Municipality of Miniota, Manitoba, with a good potential to contain a Souris-type gravel deposit and a good potential for swelling sodium bentonite.*

by T. Andrushuk of Miniota (Bannatyne, 1968a). The olive-green waxy sodium bentonite was sampled from the upper part of the Millwood Member of the Upper Cretaceous Pierre Shale. It was collected 0.8 km north of Beulah in the R.M. of Miniota (Beulah outcrop, Figure GS-18-2), within the road allowance between Sec. 7 and 18 in 15-26-W1 (Bannatyne, 1970).

In September 1967, Bannatyne (1967, 1968a, b) augered 20 holes in the road allowance. The holes indicated that the swelling bentonite beds ranged from 0 to 66 cm thick and were often found with other bentonite beds, with poorer swelling properties. Eight bentonite samples from the holes were sent to the Federal Mines Branch in Ottawa for swelling, viscosity and gel strength tests. According to Reeves (1968), the tests confirmed the high swelling index of the bentonite; the low sand content; and the reasonably high pH, yield and colloidal content; however, the viscosity and gel strength were anomalously low compared with the standard swelling bentonite from Wyoming, and therefore would not likely be a good drilling mud. However, Reeves also concluded that the high zeta potential and colloidal content, comparable to that of Wyoming bentonite, indicated that the Beulah bentonite would be a suitable binder for pelletizing iron-ore concentrates. There is no evidence that actual pelletizing tests have ever been carried out on the

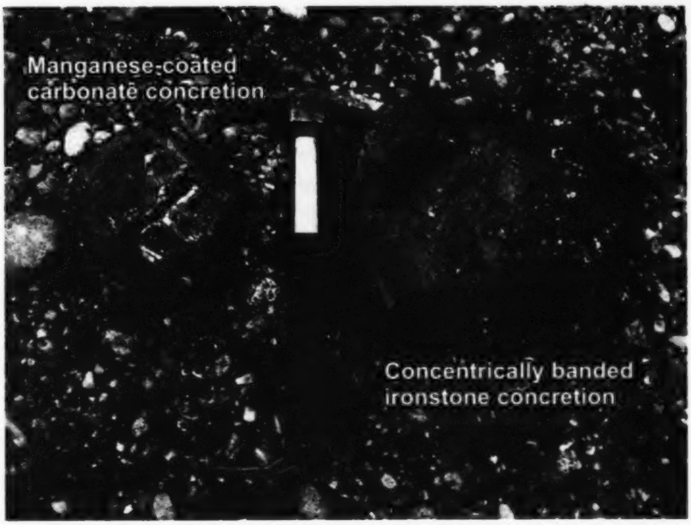
Manganese-coated carbonate concretion
Concentrically banded ironstone concretion

Figure GS-18-3: Manganese-coated carbonate concretion (left side) and concentrically banded ironstone concretion from the Armitage pit in the Assiniboine River valley, south of Miniota, Manitoba.

Beulah bentonite. In spite of the poor results described above, Bannatyne (1967, 1968a, b) suggested that detailed testing, with the proper equipment, in Sec. 7 and 18 in 15-26-W1 (held privately) might outline a deposit of swelling sodium bentonite.

In June 2007, a 10 cm thick, yellowish, partially swelling bentonite bed was seen in a ditch exposure near the northeast corner of 7-15-26-W1, at the junction of the road allowance and PTH 83. The bentonite bed is located very near auger hole no. 10 from Bannatyne (1967), where he found a 36 cm thick slightly swelling bentonite seam overlying Millwood Member shale. An attempt was also made to trace the bentonite bed, 0.4 km to the south of (and roughly parallel to) the road allowance, where a minor road passes generally east-west through the centres of NW- and NE-7-15-26-W1. At this locality, the Millwood Member is present in the bank of a small stream valley and is overlain to the east by badly fractured Odanah Member of the Pierre Shale but bentonite beds were not observed. In spite of the fact that no swelling sodium bentonite was seen within parts of 7-15-26-W1 during this brief field check, it is felt that the area west and northwest of Beulah (Figure GS-18-2) has good potential for a deposit of swelling sodium bentonite. These sections require sampling by backhoe or auger drilling, as recommended by Bannatyne (1967, 1968a, b).

Hawley dugout

Bannatyne (1968a) speculated that swelling sodium bentonite should also be present to the south of the community of Miniota. Confirmation of its presence was received in November 2006, when R. Rowan (pers. comm., 2006) indicated that he had sampled a 61 cm thick bed of swelling green waxy bentonite, about 5 km to the southwest of Miniota in the Hawley dugout (Figure GS-18-2). The bed was exposed at the base of a 2 m deep dugout, belonging to J. Hawley, in SE-16-13-27-W1. A visit to the site in June 2007 revealed that the dugout was filled with water. Auger drillholes or a backhoe adjacent to the dugout would be required to obtain additional samples. An additional area with good potential for a swelling sodium bentonite deposit is shown in Figure GS-18-2 in the vicinity of the Hawley dugout.

Potash and sodium chlorate (R.M. of Archie)

Potash

Potash is contained at depth within the Devonian Prairie Evaporite and two deposits are located south of Russell (Figure GS-18-1), east of the Saskatchewan border. The potash deposits comprise a mixture of sylvite and halite, with minor carnallite and less than 1% green clay, and are among the "cleanest" in western Canada (Bannatyne, 1971). Across the provincial boundary, in Saskatchewan, potash is used to produce a variety of fertilizer products that are sold around the world.

Russell-Binscarth area

In the early 1960s, S.A.M. Explorations Ltd. discovered potash beds in the Assiniboine River valley at a depth of 780.2 m (Bannatyne, 1983; Assessment File 98068, Manitoba Science, Technology, Energy and Mines, Winnipeg). The discovery hole was drilled in 7-15-19-29-W1, south of Russell and west of Binscarth. The Russell-Binscarth deposit (Figure GS-18-1) eventually became to be known as the Manitoba Potash Project, for which a 1987 comprehensive feasibility study indicated probable mineable ore reserves of 154.2 million tonnes grading 24.5% K_2O in sylvite (The Northern Miner, 1990). Although the study was done for an area north of the R.M. of Archie, additional drilling was carried out in the potash permit, which indicated that potash mineralization might extend to the south into the St-Lazare–McAuley area.

St-Lazare–McAuley area

In May 1964, Baycourse Mines Limited acquired a 10 117 ha potash exploration permit near St-Lazare (Figure GS-18-1) on mainly privately held mineral rights to the south of the Russell-Binscarth area. In the same year, the company became a subsidiary of Metal Mines Limited (which undertook and financed drilling of the property) and changed its name to Prairie Potash Mines Limited. After three holes had been completed into the potash bed, The International Nickel Company of Canada Limited (Inco Limited.), through its subsidiary Canadian Nickel Company Limited, took an option on the property to conduct further drill testing. As a result of this work, Inco Limited earned a 65% interest in Prairie Potash Mines Limited (The Northern Miner, 1966). Prairie Potash Mines Limited estimated it had outlined sufficient reserves to supply a plant with 907 000 tonnes of muriate of potash (KCl) annually for at least 50 years (The Northern Miner, 1966). The company undertook a feasibility study but did not develop the property and their lease lapsed in July 1977.

Most of the drilling that outlined the St-Lazare–McAuley deposit was done north of the R.M. of Archie; however, two of the holes were drilled within the R.M. of Archie (in 4-32-15-28-W1 and 4-36-15-29-W1, Figure GS-18-4). Both holes penetrated the main potash bed (Assessment File 96058, Manitoba Science, Technology, Energy and Mines, Winnipeg). The eastern hole was included by Bannatyne (1983) in his calculation of the reserves of the St-Lazare–McAuley deposit in 1983. A "stratigraphic" reserve of 510 million tonnes averaging 22.0 % K_2O, with a cutoff grade of 18% K_2O, was estimated using the best 2.44 m of the Esterhazy Member.

Additional potash potential adjacent to the St-Lazare–McAuley deposit was also calculated by Bannatyne (1983) in 15-29-W1 using a virtual or 'dummy' testhole. His Block 3 (Figures GS-18-1, -4), almost totally within the R.M. of Archie, was estimated to contain 170 million tonnes grading 20% K_2O in sylvite. Potash potential was also indicated for the southern portion of Block 2 in 15-28-W1. Block 3 and Block 2 are separated by drill-proven reserves of the southernmost portion of the St-Lazare–McAuley deposit. All are included in Figure GS-18-4 showing the area of the R.M. of Archie that has a good potential for containing a potash deposit.

In September 2005, a Potash Exploration Permit (QP-154) was issued to Agrium Inc. for much of the area (45 212 ha) formerly investigated by Prairie Potash Mines Limited. Additional ground to the southeast has been applied for by W.S. Ferreira Ltd. under QP-168. These permits include the area of good potential that is shown in Figure GS-18-4. If these holdings have been worked on, no information has become available due to confidentiality reasons.

Sodium chlorate

Sodium chlorate ($NaClO_3$) is produced at Brandon and Hargrave, located west of Virden (Figure GS-18-1), by an electrolytic chemical reaction from sodium chloride (NaCl) brine. The brine is either derived by dissolving a salt bed in the subsurface or produced from sodium chloride feedstock, obtained as a byproduct of a potash operation. The major use of sodium chlorate is in the paper industry, where it is used to generate chlorine dioxide (ClO_2), a key bleaching agent necessary to produce paper from wood pulp. Other sodium chlorate applications include mining (vanadium and uranium), agriculture (herbicides and defoliants) and chemical synthesis (rocket propellants and dyes).

Nexen Inc.

Nexen Inc., the biggest producer of sodium chlorate in the world, has purchased crystallized salt for its plant in Brandon (Figure GS-18-1) from The Canadian Salt Company Ltd. in Belle Plaine, Saskatchewan, for the past 27 years. The evaporated salt is derived as a byproduct from potash production. However, it should be noted that in 2004, Nexen Inc. obtained five quarry leases to solution mine salt from the Prairie Evaporite in the vicinity of ERCO Worldwide's sodium chlorate plant near Virden (see below).

As of October 2004, Nexen's Brandon plant production capacity was increased, at a cost of $60 million, to 263 300 tonnes of sodium chlorate per year, making it the world's largest producer. And thanks to low electrical rates, which account for 70 to 90% of the variable manufacturing cost of producing sodium chlorate, it is also one of the lowest cost facilities in North America. In 2004, the average cost of electricity delivered to the Brandon plant was approximately $25/MWh, and in the first six months of 2005 it averaged $27/MWh. Approximately 67 unionized and salaried personnel worked at the Brandon facility in 2005 (Canexus Income Fund, 2005).

ERCO Worldwide (a division of Superior Plus Income Fund)

In 2001, Albchem Manitoba Ltd. drilled two wells 1200 m into the Prairie Evaporite, near Hargrave, a few kilometres west of Virden (Figure GS-18-1). Solution mining began in 2002 with one well used to inject water into the salt bed, and the other to recover the brine. Albchem's decision to build its $40 million plant (with a capacity of 40 000 tonnes of sodium chlorate per year) in Manitoba was strongly influenced by low electrical rates.

In 2003, the property was acquired by ERCO Worldwide, a division of Superior Plus Income Fund, for $120 million as part of a larger package. The purchase increased ERCO Worldwide's total sodium chlorate production capacity by 120 000 to 580 000 tonnes, and raised its share of the estimated North American capacity from 23 to 29%.

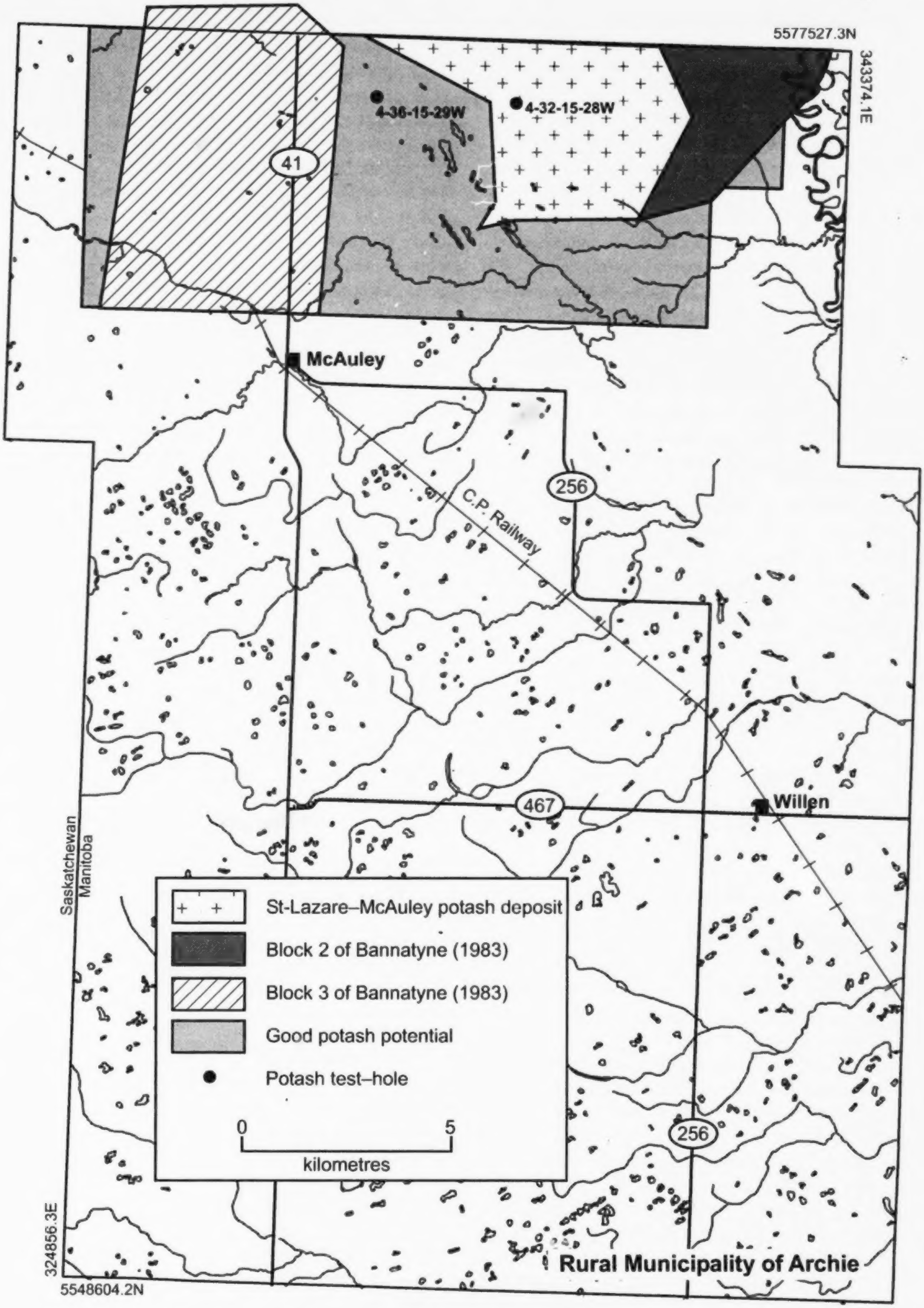
5577527.3N
343374.1E
4-36-15-29W
4-32-15-28W
41
McAuley
256
C.P. Railway
467
Willen
Saskatchewan
Manitoba
St-Lazare–McAuley potash deposit
Block 2 of Bannatyne (1983)
Block 3 of Bannatyne (1983)
Good potash potential
Potash test–hole
0
5
kilometres
256
324856.3E
5548604.2N
Rural Municipality of Archie

Figure GS-18-4: *Rural Municipality of Archie, Manitoba, showing two testholes within an area having good potash potential.*

Manganese (R.M. of Rossburn)

Manganese is used to produce steel alloys and for many nonmetallurgical uses, which include water treatment and the production of batteries, tiles, ceramics and glass. In the spring of 1940, manganese was found, for the first time in Manitoba, in the vicinity of Mears (Figure GS-18-5), on the farm of J. Maydaniuk in NW-26-21-24-W1 (locality 1) in the R.M. of Rossburn (Spector, 1941a, b). Five other occurrences were found in the same township, mainly along the trend of the Birdtail Creek valley. One other occurrence was found within Riding Mountain National Park, about 11 km north of Mears.

During the summer of 2007, attempts were made to visit the manganese occurrences in Sec. 26 and 35, Twp. 21, Rge. 25, W 1st Mer. (localities 1-4), a description of them has been summarized from Spector (1941a, b), see below. Two occurrences were not visited due to a lack of time; however, information on these sites is available in Spector (1941a, b). The occurrence within Riding Mountain National Park cannot be developed, and is not discussed further.

Spector (1941a) reported that two manganese occurrences were exposed in a trench and several shallow pits in NW-26-21-24-W1 (Figure GS-18-5). The northern occurrence (locality 1) was estimated to be 3.7 m^2 in area with a maximum thickness of 20 cm and containing 30.22% Mn, after drying. The southern occurrence (locality 2) comprised three lenses from 0.9 to 3.0 m in length containing an average of 39.91% Mn, after drying. Also according to Spector, two other manganese occurrences were exposed, one in a trench in NE-35-21-24-W1 (locality 3) and one in several shallow pits in SW-35-21-24-W1 (locality 4, Figure GS-18-5). The occurrence in the northeast quarter section (locality 3) was exposed in a 15.2–40.6 cm thick seam beneath 2.5–20.3 cm of overburden within a 13.7 m long trench near the base of a hill, where a spring is present. A sample from the seam assayed 45.85% Mn, after drying. The lenticular occurrence in the southwest quarter section (locality 4) was at least 16.8 m long, up to 6.10 m wide and varied in thickness from 15.2 cm near the edge to 1.67 m near the middle. Dawson (1942) estimated the occurrence to contain about 91 tonnes of manganese ore of possible chemical grade.

According to Spector (1941a, b) and Dawson (1942), the Recent "wad or bog" manganese occurrences originated, since the last glaciation, from leached manganiferous iron carbonate ("ironstone") nodules or concretions, contained within the Cretaceous Pierre Shale. The nodules were leached by carbonated water that carried the manganese in solution as manganese bicarbonate. The manganese bicarbonate was then precipitated as manganese oxide, after exposure to the atmosphere, at or near spring openings present at the base of Birdtail Creek.

As mentioned earlier, the locations of the trenches and pits for the four occurrences (localities 1 to 4; Spector, 1941a) were visited in June 2007 but after over 60 years of exposure there was no evidence of manganese mineralization at surface. However, in view of the previous work, there is still good potential that a significant manganese deposit could be found, especially with a drilling program, in the areas shown in Figure GS-18-5. Manganese is also present in water wells situated in the vicinity of Birdtail Creek (J. and R. Kucey, pers. comm., 2007). The manganese, which stains porcelain fixtures black, is removable from the water by filtration methods. Perhaps, a method to recover the manganese in economic concentrations and, at the same time, produce palatable drinking water, may be possible.

Kuzenko gravel pit

In June 2007, a 3–5 cm thick seam of possibly dark black manganese(?)-rich silt (Figure GS-18-6) was sampled at the top of the lowermost bench in the Kuzenko gravel pit (Figure GS-18-5) within 11-2-21-25-W1. The gravel pit is located within a series of low hills on the west valley wall of Birdtail Creek in the R.M. of Rossburn. The shale-rich outwash gravel in the pit contains numerous clasts of manganese-coated carbonate rock, as well as nearly solid manganese concretions. The dark black silt seam stands out against the generally light buff gravel seen in the majority of the pit, and seems to be unique. This may suggest that the silt was deposited in the steam bed as a placer deposit; or possibly may represent an old soil profile with manganese enrichment, due to a high water table. A sample will be analyzed to determine the manganese concentration in the silt. Assuming the results will be positive, the vicinity of the Kuzenko gravel pit is considered to have a good potential for manganese mineralization (Figure GS-18-5).

Economic considerations

The major economic driver of the rural municipalities of Miniota, Archie and Rossburn is agriculture. The development of local industrial minerals would help to diversify the economic base of the rural municipalities. These developments could range from small (rock collecting site) to medium (swelling sodium bentonite or manganese extraction, or sodium chlorate manufacturing) to large (potash mine):

- There is an opportunity to develop a rockhound collecting site in the R.M. of Miniota, in the vicinity of the Armitage pit located to the south of the community Miniota, similar to that presently operating at Souris, Manitoba.
- A local source of swelling sodium bentonite within the R. M. of Miniota, a first for Manitoba, could possibly replace imported material. A variety of products from drilling mud to pond liners to cat litter could be produced from the bentonite.
- Small quantities of chemical grade manganese (a first

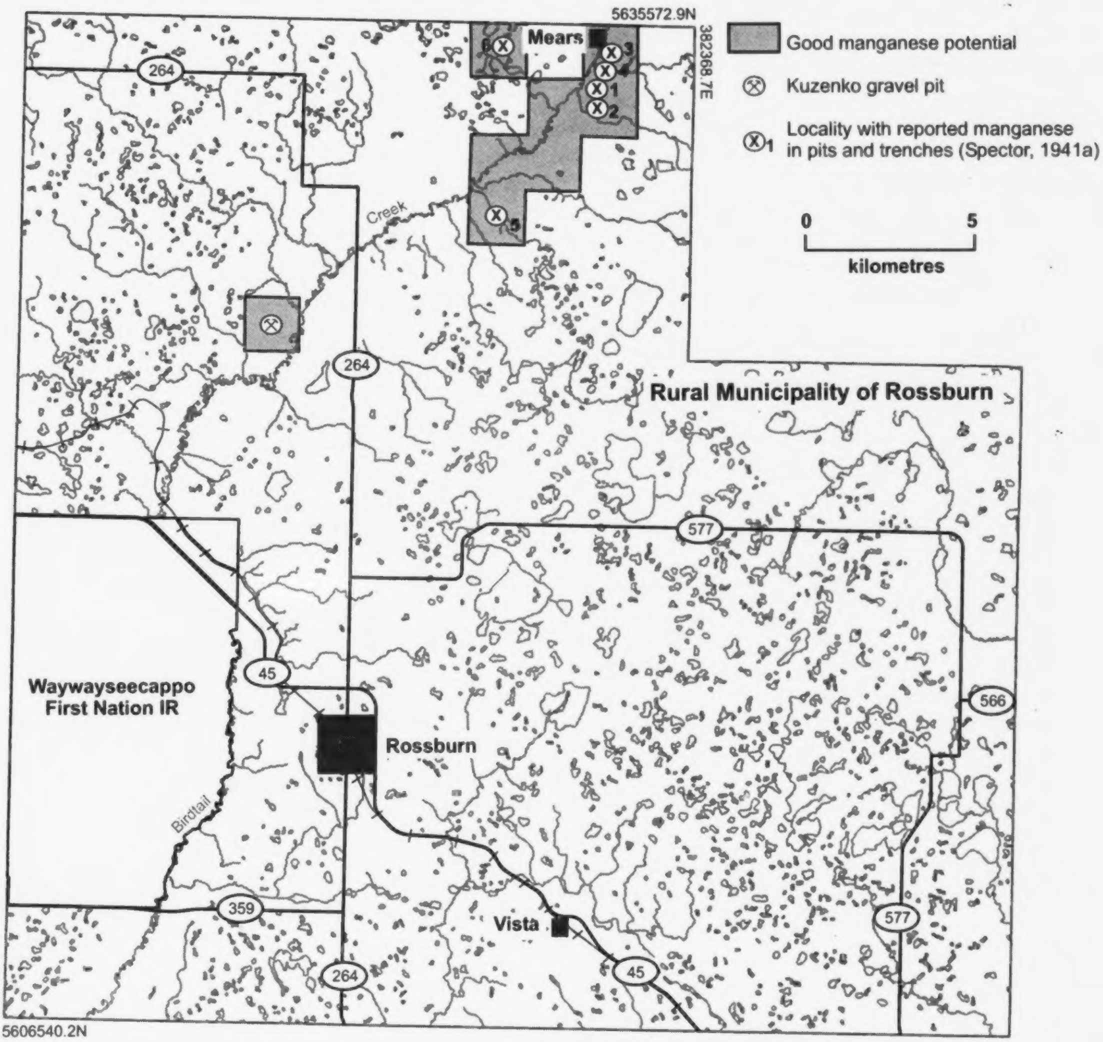
5635572.9N
382368.7E
Good manganese potential
Kuzenko gravel pit
Locality with reported manganese in pits and trenches (Spector, 1941a)
0
5
kilometres
Mears
1
2
3
4
5
6
Creek
264
577
566
45
359
Rural Municipality of Rossburn
Waywayseecappo First Nation IR
Rossburn
Birdtail
Vista
362020.9E
5606540.2N

__Figure GS-18-5:__ Rural Municipality of Rossburn, Manitoba, showing areas with good manganese potential.

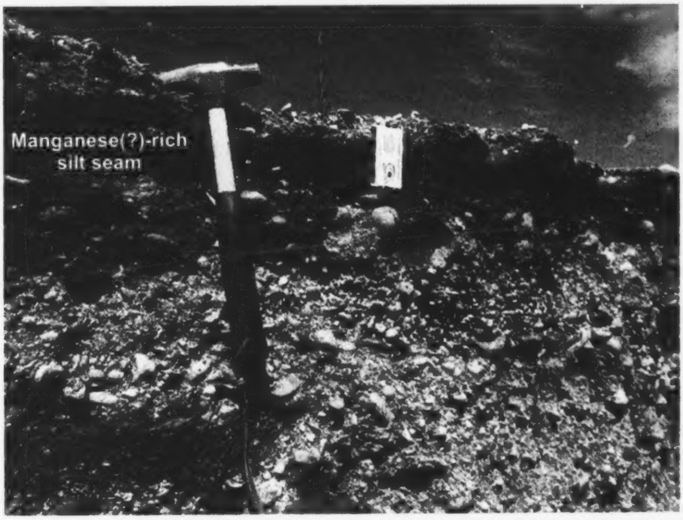
Manganese(?)-rich silt seam

__Figure GS-18-6:__ Dark black manganese(?)-rich silt seam situated at the top of the lowermost bench of the Kuzenko gravel pit in 11-2-21-25-W1 in the Rural Municipality of Rossburn, Manitoba. The bottom of the scale card marks the base of the seam.

for Canada) could possibly be selectively mined in the vicinity of Birdtail Creek in the R.M. of Rossburn. Another option may be to recover the manganese from groundwater. Manganese is used to alloy steel and in a variety of nonmetallurgical uses, such as battery, tile, ceramic and glass production and water treatment.

- A mineable potash deposit and fertilizer production within the R.M. of Archie would provide a major economic stimulus to the municipality. A potash mine would rival a metal mine in northern Manitoba at today's potash spot price.
- A sodium chlorate plant could be built in the R.M. of Archie, adjacent to a new potash mine, to directly use the sodium chloride byproduct to produce sodium chlorate for the paper industry. Manitoba's low electrical rates also make this a particularly attractive proposition. Or, the mine could supply the world's largest sodium chlorate plant in Brandon with Manitoba-mined feedstock.

Acknowledgments

J. and R. Kucey, residents of the R.M. of Rossburn, are thanked for providing access to Birdtail Creek valley, near Mears, Manitoba. B. Lenton is gratefully acknowledged for preparing the figures in this report. H. Groom and R. Bezys reviewed the manuscript and provided many constructive comments.

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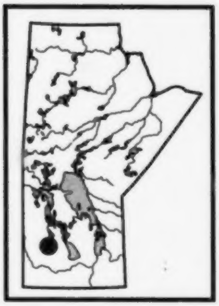
GS-19 Aggregate resources in the Rural Municipality of Park, Manitoba (NTS 62J12, K9)

by H.D. Groom

Groom, H.D. 2007: Aggregate resources in the Rural Municipality of Park, Manitoba (NTS 62J12, K9); *in* Report of Activities 2007, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 195–201.



Summary

The Rural Municipality (R.M.) of Park was mapped in 2007 to update aggregate information for land-use planning in the area. The landscape of small lakes and rolling hills, as well as proximity to Riding Mountain National Park, has resulted in increased recreational development, which has put increasing land-use pressure on aggregate deposits in some parts of the municipality. The last study of this rural municipality was completed in 1980 and current information is required for sound land-use planning decisions. The information gathered will be included in municipal development plans and used for resource management within Manitoba Science, Technology, Energy and Mines.

The R.M. of Park has large reserves of aggregate in glaciofluvial deposits spread across the municipality. The deposits were formed during deglaciation as ice stagnated and aggregate was deposited over and within melting blocks of ice. As a result, the deposits are characteristically quite variable in depth and sediment type over short distances. Shale and ironstone concretions eroded from the underlying bedrock are significantly deleterious and lower the quality of the aggregate. The gravel is best suited to low-end products, such as traffic gravel, which tolerates a moderate percentage of shale.

There are only four active pits in the municipality, which reflects the low quality of the deposits. Two of them were active in 1980, when the last aggregate study was carried out, and are still not depleted after years of extraction. This reflects the substantial depth of material in some parts of the deposits and the sheer volume of aggregate per quarter section in those areas. The greatest demand for sand and gravel is in the eastern part of the municipality, near the south gate of Riding Mountain National Park. Cottage developments and recreational facilities, such as golf courses, are on the increase there and they are being built on aggregate deposits, however, the volume of aggregate in the areas of the nearby active pits (HD245 and HD222) is more than adequate to meet the needs for the foreseeable future. Land-use planning decisions should be based on maintaining a buffer around these pits to prevent any development from limiting their expansion in the future.

Introduction

An aggregate inventory of the R.M. of Park was carried out in the summer of 2007. The information gathered is included in municipal development plans, used for resource management within Manitoba Science, Technology, Energy and Mines and is available to other government departments and outside clients on request. The municipality was originally mapped in 1980 as part of the South Riding Mountain area (Groom, 1980a–c).

The R.M. of Park is located in west-central Manitoba, adjacent to the south boundary of Riding Mountain National Park (Figure GS-19-1). Until recently, the R.M. of Park comprised two discrete blocks of land. The northern block covers three townships, parts of Twp. 29 and 30, Rge. 28–29, W 1st Mer., and lies adjacent to the R.M. of Shell River; it was incorporated into that municipality on January 1, 2007. The southern block forms the current R.M. of Park; it covers approximately six townships, parts of Twp. 19 and 20, Rge. 18–22, W 1st Mer., and is located on NTS sheets 62J12 and K9.

Provincial highway 10, Provincial roads 250, 262, 270, 354, 470 and 566, and a network of section roads give good access to most of the area. The largest village in the municipality is Onanole but the major service centre is the city of Dauphin, which is accessed by Highway 10 through the park. The primary industries have historically been mixed farming and forestry. However, the landscape of small lakes and rolling hills, as well as proximity to the national park, has resulted in an increase in seasonal cottagers and tourists so that recreational-related service industries now form an important part of the local economy.

Previous work

The bedrock of the area has been described in many regional studies, including those by Wickenden (1945), Bannatyne (1970) and McNeill and Caldwell (1981).

The municipality is covered by two reports on groundwater availability: Neepawa area (NTS 62J; Betcher, 1989) and Riding Mountain area (NTS 62K; Sie, 1978). These reports contain 1:250 000 scale maps of bedrock geology, surficial geology and overburden thickness as well as maps more directly related to water resources.

Klassen (1979) outlined the glacial history and mapped the surficial geology of NTS sheets 62K (Riding Mountain) and 62N (Duck Mountain) at a scale of 1:250 000; the western portion of the municipality is included in this report. The R.M. of Park was mapped at a scale of 1:50 000 as part of a surficial geology and aggregate mapping project that included five municipalities (Groom, 1980a–c). During that study, 97 sites were examined in the R.M. of Park; 82 of these were

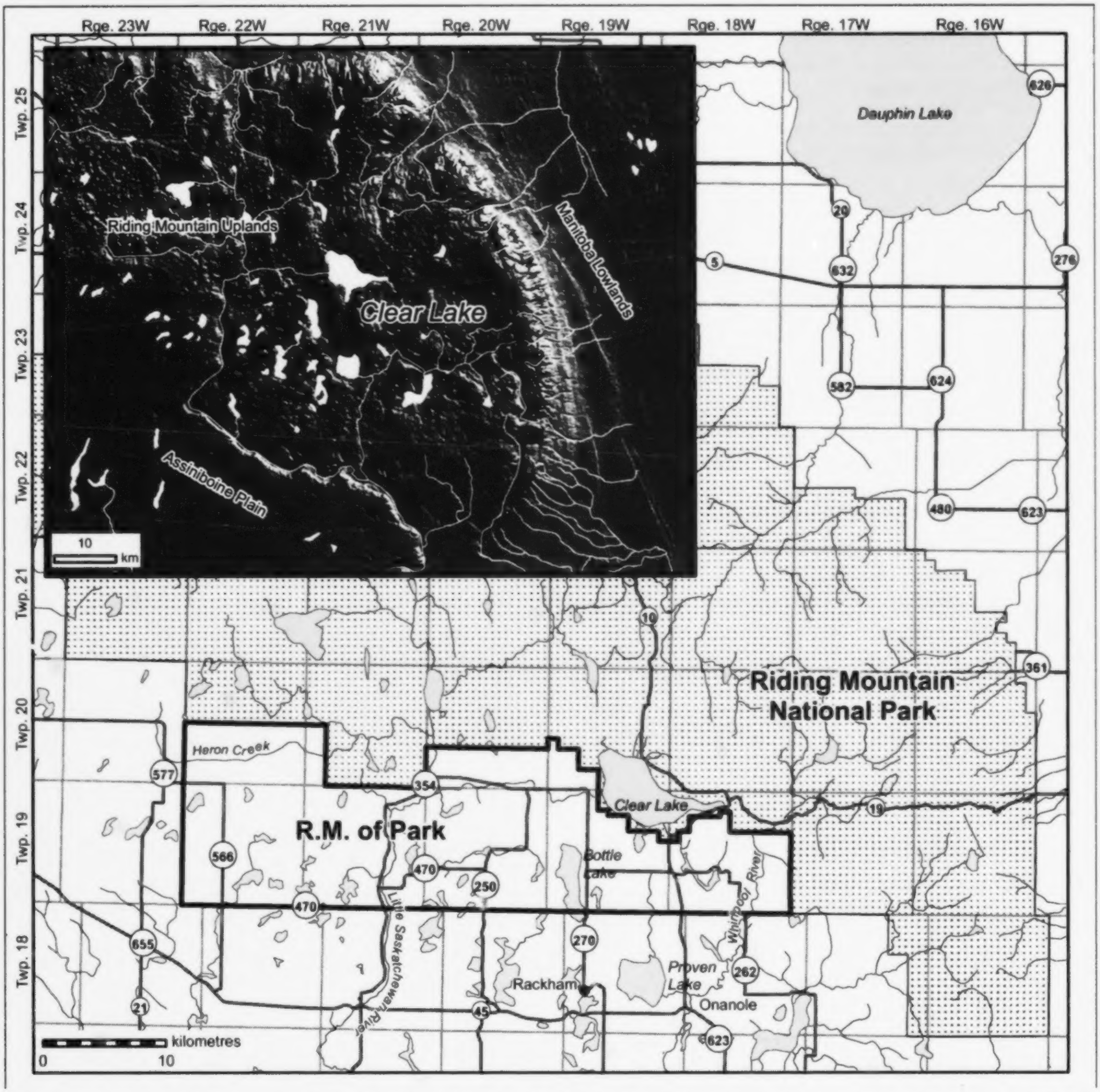

Rge. 23W
Rge. 22W
Rge. 21W
Rge. 20W
Rge. 19W
Rge. 18W
Rge. 17W
Rge. 16W
Twp. 25
Twp. 24
Twp. 23
Twp. 22
Twp. 21
Twp. 20
Twp. 19
Twp. 18
Riding Mountain Uplands
Manitoba Lowlands
Clear Lake
Assiniboine Plain
10
km
Dauphin Lake
Riding Mountain National Park
Heron Creek
R.M. of Park
Clear Lake
Bottle Lake
Little Saskatchewan River
Whirlpool River
Rackham
Proven Lake
Onanole
626
20
5
632
276
582
624
480
623
10
361
577
354
19
566
470
250
470
270
655
262
21
45
623
kilometres
0
10

Figure GS-19-1: Location map of the Rural Municipality of Park, Manitoba. Inset figure shows hummocky terrain of Riding Mountain uplands.

aggregate sites. Thirteen backhoe pits were dug in the municipality. Aggregate data from that project was published as an open file report accompanied by a 1:100 000 scale aggregate map (Young, 1983). The municipality is also included on two recent 1:250 000 scale Surficial Geology Compilation Maps: SG-62J (Matile and Keller, 2004a) and SG-62K (Matile and Keller, 2004b). On these maps, the surface units have been draped over topographic relief maps and landforms are very clearly shown.

Geology

Bedrock geology

The municipality is underlain by the Odanah Member of the Upper Cretaceous Pierre Shale (Bannatyne, 1970). Bannatyne included the Odanah Member, along with the underlying Millwood Member, as part of the Riding Mountain Formation. However, McNeill and Caldwell (1981) rejected the Riding Mountain Formation nomenclature and placed the Odanah and Millwood members into the Pierre Shale. The Odanah Member consists of hard, grey, siliceous shale; ironstone concretions are common and iron or manganese staining often occurs on fractures or bedding planes. The bedrock is overlain by 20 to >125 m of Quaternary sediment (Sie, 1978; Betcher, 1989) and there were no bedrock outcrops observed in the municipality. The bedrock section reported by Bannatyne (1970) in Sec. 18, Twp. 19, Rge. 18 W 1st Mer.

(abbreviated 18-19-18-W1) is no longer exposed. McNeill and Caldwell (1981) describe the Odanah Member sedimentary rocks in sections north, south and west of the study area. Bannatyne (1970) describes the chemical properties and economic potential of the unit. Odanah Member shale clasts are a common component in the till and gravel of the R.M. of Park.

Surficial geology and late glacial history

The surficial sediment in the municipality is primarily till, glaciofluvial sand and gravel (including ice-contact and outwash deposits), and glaciolacustrine sand, silt and clay. The units are shown on Figure GS-19-2.

The surface till in Riding Mountain uplands is the Zelena Formation. The till has a brownish clay-silt matrix with moderate carbonate content and contains a pebble lithology of shale, Precambrian and carbonate clasts. It is generally 3–15 m thick but locally can be much thicker (Klassen, 1979). The till forms a hummocky stagnation moraine with hummocks ranging between 5 and 15 m high. The till is a lateral equivalent of the Lennard Formation, which is the surface till on the Assiniboine River plain. These tills overlie the Early Wisconsinan Minnedosa Formation. The Minnedosa Formation till is an olive-brown, clayey till that is usually more compacted and less calcareous than the tills of the Zelena and Lennard formations.

Glaciofluvial deposits form the majority of the surficial sediment in the municipality. These deposits consist of three types: ice-contact kame-esker complexes, outwash plains deposited over stagnant ice and outwash terrace deposits along meltwater channels. The sediment consists of a wide range of grain size (from sand to boulders) and of varying depths (>18 m for some deposits). The sand and gravel is most often crossbedded, the beds are often faulted and seams of flow till are common, indicating fluvial deposition in close contact with ice. Shale content ranges from 10 to 90% and is present in all of the deposits; ironstone concretions and weathered Precambrian clasts are also present in most of the gravel pits examined.

There are two kame-esker complexes in 19-20-W1 (Figure GS-19-2). The complexes are broadly curvilinear features formed of ridges that are up to 30 m high; the complexes are 0.5–1.5 km wide. One segment runs broadly east-west for 12 km; the other, approximately perpendicular to the first, runs south along Bottle Lake for 8 km. A narrow band of outwash, oriented southeast, separates the two segments. The outwash plains have hummocky surfaces with local relief of 3–9 m. The outwash terrace deposits occur as flat benches along Little Saskatchewan and Whirlpool rivers and Heron Creek.

Glaciolacustrine sediment (fine sand, silt and clay) occurs near Bottle and Proven lakes. Much of this material was deposited over stagnant ice in short-lived glacial lakes; hummocks of flat-bedded silt are exposed near the town of Rackham just south of the study area. This 'inverted topography' resulted when silt, originally deposited in holes between ice blocks, was left as hills when the ice melted away.

Late glacial history

Klassen (1979) outlined the general sequence of events during the Wisconsinan glaciation in the Duck and Riding mountains area. During the Late Wisconsinan, the Riding Mountain area was glaciated by ice flowing from northwest centres of outflow. Klassen states that the Zelena till was deposited on the uplands (above the 580 m asl contour) by ice that flowed from a slightly more northerly centre than the ice that deposited the laterally equivalent Lennard till on the adjacent Assiniboine River plain. During deglaciation, ice began to stagnate on the

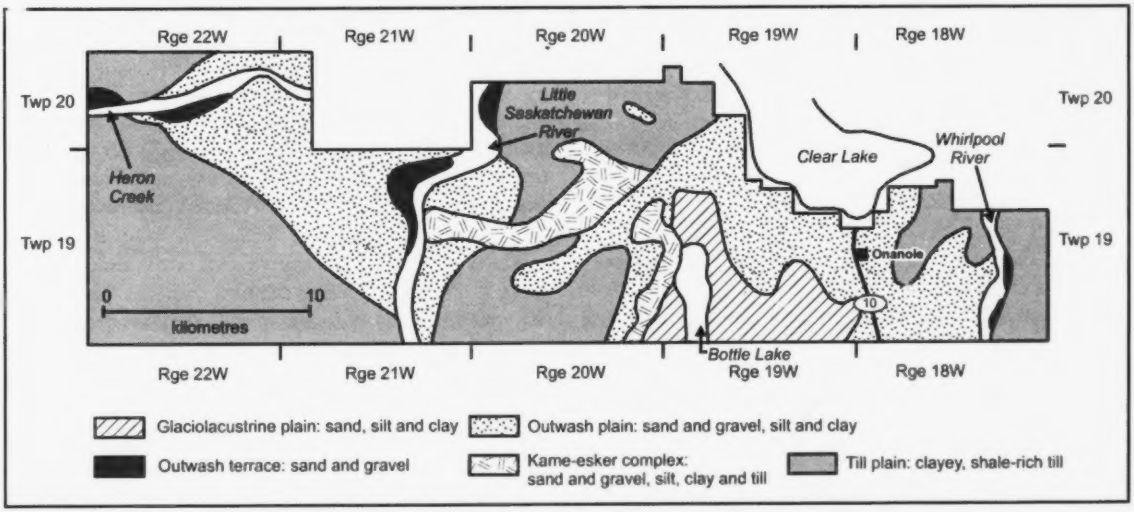

Rge 22W
Rge 21W
Rge 20W
Rge 19W
Rge 18W
Twp 20
Twp 19
Heron Creek
Little Saskatchewan River
Clear Lake
Whirlpool River
Onanole
10
Bottle Lake
0
10
kilometres
Glaciolacustrine plain: sand, silt and clay
Outwash plain: sand and gravel, silt and clay
Outwash terrace: sand and gravel
Kame-esker complex: sand and gravel, silt, clay and till
Till plain: clayey, shale-rich till

Figure GS-19-2: Surficial geology of the Rural Municipality of Park, Manitoba.

upland area while active ice continued flowing at the lower elevations on both the east and southwest sides of the mountain.

As the ice sheet stagnated, a chaotic landscape resulted from debris melting out of the ice and meltwater trying to escape to lower elevations, but being prevented by thick ice still occupying those areas. There were blocks of ice with crevasses between and debris was slumping off into the crevasses while water was flowing or ponding. These processes formed hummocks of till, gravel, silt or a mixture of all three. The kame-esker complexes formed in openings within the ice or against margins of stagnant ice blocks. Outwash plains formed as water escaped across the ice, depositing sand and gravel. The large amount of silt and clay around Proven and Bottle lakes was deposited over the ice in glacial Lake Proven, the largest of many short-lived supraglacial lakes formed when surrounding ice and debris prevented meltwater from flowing.

As drainage became established, Little Saskatchewan River, Whirlpool River and Heron Creek became the major channels carrying meltwater from the area. Sand and gravel deposits, referred to as glaciofluvial or outwash terraces, formed along the edges of these waterways.

Aggregate inventory

Methodology

The aggregate inventory was carried out in two stages: office compilation followed by fieldwork. Previously mapped deposits were transferred onto 1:20 000 township photomosaics and a 1:50 000 photo base of the municipality created from 1998 orthophotos. The township mosaics were used as a base on which to compile aggregate information from several sources:

1) active pit and quarry locations – Mines Branch quarry database;
2) lease and withdrawn locations – Mines Branch plat books and digital shapefiles;
3) Crown versus private ownership – Manitoba Crown Lands Branch database;
4) pit and sample locations – Geological Survey Pleistocene database;
5) pit and sample locations – Department of Highways block files; and
6) existing aggregate maps and reports.

Gravel pits, roadcuts and natural exposures were examined during the first part of the field examination. Pits were examined for type of material, degree of depletion and active/inactive/depleted status. Special note was taken of shale content as it can make a deposit unsuitable for certain end uses (e.g., concrete). Unopened portions of deposits were inspected and land uses that would limit aggregate extraction noted. Site locations were taken by GPS using UTM co-ordinates, as well as by section-township-range notation. No bedrock outcrops were located during the survey. During the 1980 study of the Riding Mountain area (Groom, 1980a–c), gravel deposits were extensively sampled. Forty-five samples were collected in the R.M. of Park and returned to Winnipeg for sieve analysis and pebble lithology counts. Grain sizes greater than pebbles (>50 mm) were not included in the sieve analysis, but a visual estimate of that fraction was made on site. Sieve results are summarized in Table GS-19-1. Sample sites are shown on Figure GS-19-3; for clarity the two letter prefix (HG) of the sample sites has been omitted on the diagram. Pebble lithology was done on the 4–16 mm size fraction; pebbles were divided into shale, carbonate and Precambrian classifications and not further subdivided. It is very difficult to accurately determine the shale content of a sample because shale breaks so easily. Pebble counts can give an estimate of the shale content, but it is not a really accurate method. A weight percent of the shale in the 4–16 mm fraction was also determined. As expected, pebble counting overestimates the percent shale, but the relationship was not consistent.

Aggregate resources

Aggregate resources in the R.M. of Park are found in three types of deposits: kame-esker complexes, outwash plains and outwash terraces. These deposits form the surface material for at least one-half of the municipality (Figure GS-19-2). All the deposits contain shale; ironstone concretions and weathered Precambrian clasts are also common. There are four active gravel pits. The aggregate in these pits is privately owned and the pits are spaced evenly across the municipality: SW-5-19-18-W1 (HD245), NE-32-19-19-W1 (HD222), SW-21-19-20-W1 (HD229) and NW-19-19-21-W1 (HD233). Two of these pits were active in 1980 (HD222 and HD233) and the other two are in the same quarter-sections as pits that were visited in 1980. Most of the sand and gravel rights in the municipality are privately held. There are only two quarry leases, both in W-15-19-18-W1. There are no exposures in the lease areas but ditch exposures indicate 2–3 m sandy fine pebble gravel overlying till.

Aggregate deposits

There are two kame-esker complexes in the municipality, both in 19-20-W1 (Figure GS-19-2). The sediment forming the deposits is not well exposed. The thickest exposure is 7 m of sediment, while the total height of the feature exceeds 30 m in places. Four exposures in the south-trending segment along Bottle Lake and 12 exposures in the east-trending segment indicate that at least the upper portions of the complexes are primarily formed of crossbedded sand and sandy fine pebble gravel; shale content is very high. Silt beds and lenses of till are also common in the sediment. Faulting of the beds and the close association of beds of greatly different grain size indicate the ice-contact origin of these features. There is one active pit (HD229 in SW-21-19-20-W1) in these deposits. The pit is up to 7 m deep in places. The material

Table GS-19-1: Summary table of sieve data and shale content of aggregate samples, Rural Municipality of Park, Manitoba (Groom 1980a–c).

Twp.-Rge.	Site	Deposit type	% Pebbles[1]	% Granules[2]	% Sand[3]	% Silt/Clay[4]	% Shale[5]	Wt % Shale[6]
19-20W1	HG002	kame-esker	19	16	63	2	60	81
19-20W1	HG006	kame-esker	38	11	50	1	54	27
19-20W1	HG008	kame-esker	36	13	49	2	32	12
19-20W1	HG009	kame-esker	4	3	90	3		
19-20W1	HG067	kame-esker	40	18	37	5	24	24
19-20W1	HG068	kame-esker	59	10	29	2	13	11
19-20W1	HG090	kame-esker	3	4	91	2	81	
19-20W1	HG098	kame-esker	13	6	79	2	22	23
19-20W1	HG109	kame-esker	49	13	36	2	11	
20-20W1	HG108	kame-esker	37	10	46	7		
19-18W1	HG151	outwash plain	18	10	70	2	33	29
19-18W1	HG152	outwash plain	30	10	52	8		
19-18W1	HG154	outwash plain	29	16	53	2	10	
19-18W1	HG162	outwash plain	49	10	37	4		
19-18W1	HG170	outwash plain	37	13	46	4	20	6
19-18W1	HG173	outwash plain	25	15	58	2		
19-18W1	HG174	outwash plain	40	14	43	3		
19-18W1	HG188	outwash plain	52	15	31	2	10	3
19-19W1	HG003	outwash plain	21	15	63	1	52	50
19-19W1	HG004	outwash plain	15	8	76	1	52	39
19-19W1	HG005	outwash plain	54	10	34	2		
19-19W1	HG014	outwash plain	62	9	27	2	56	33
19-19W1	HG080	outwash plain	31	13	55	1	17	47
19-19W1	HG081	outwash plain	50	9	40	1	15	11
19-19W1	HG146	outwash plain	41	18	39	2		
19-19W1	HG149	outwash plain	14	8	76	2	71	71
19-19W1	HGB14	outwash plain	29	12	54	5	43	33
19-21W1	HG010	outwash plain	41	9	46	4	9	4
19-21W1	HG011	outwash plain	51	8	29	12	7	5
19-21W1	HG012	outwash plain	55	17	25	3	57	40
19-21W1	HG013	outwash plain	44	18	30	8	11	6
19-22W1	HG054	outwash plain	20	6	73	1	29	10
19-22W1	HG073	outwash plain	46	22	30	2	5	3
19-22W1	HG074	outwash plain	19	10	69	2	20	17
20-19W1	HG096	outwash plain	44	14	40	2	6	4
20-21W1	HG049	outwash plain	36	13	49	2	46	38
20-22W1	HG050	outwash plain	57	9	33	1	5	1
20-22W1	HG051	outwash plain	49	14	34	3	5	10
20-22W1	HG052	outwash plain	52	14	31	3	14	10
20-22W1	HG059	outwash plain	24	15	59	2	22	11
19-18W1	HG200	terrace	45	12	36	7	8	2
19-21W1	HG079	terrace	30	5	62	3	14	8
20-20W1	HG069	terrace	22	11	66	1	12	10

Notes: [1] 4.7–50.0 mm; [2] 2.3–4.7 mm; [3] 0.07–2.3 mm; [4] <0.07 mm; [5,6] 4–16 mm fraction

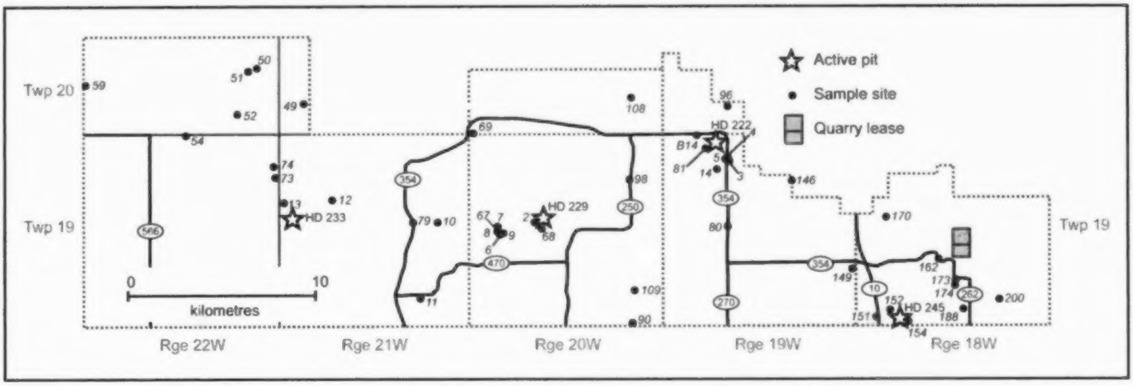


Figure GS-19-3: *Gravel pit and sample sites, Rural Municipality of Park, Manitoba (Groom 1980a–c).*

ranges from shaly sandy coarse pebble gravel to faulted beds of coarse sand interbedded with thin silt beds; there are large lenses of till in the walls and there are stockpiles of cobble-size shale clasts on site. In 1980, a pit (HG002) in the same quarter-section was 6 m deep but has been rehabilitated and is now a shallow depression. Lithology and grain size analysis for two samples from this quarter section (HG002 and HG068) are given in Table GS-19-1.

The outwash plains are the most extensive aggregate deposits in the R.M. of Park. There is one large deposit lying between Heron Creek and Little Saskatchewan River and another along the south shore of Clear Lake (Figure GS-19-2). In addition, there are numerous small patches of outwash throughout the municipality. All the sediment was deposited over stagnating ice resulting in a hummocky surface expression with local relief up to 9 m, and quite variable depths and types of material in close association with each other. Shale content is variable but is present in all sites. For the two large outwash deposits, there appears to be a broadly overall trend to fining to the southeast in each deposit, indicating a proximal-distal relationship of the sediment within the deposits. However, the chaotic nature of sediment deposited through ice stagnation, makes any such distinction quite tenuous. Three of the four active pits in the municipality are in these outwash deposits.

The pit at site HD233 in NW-19-19-21-W1 was active in 1980 and is still a major source of aggregate. The pit has greatly expanded; the active area is now at the west end of the pit. The pit face exposes 3 m of crossbedded sandy fine pebble gravel. Clay seams, till balls, shale and iron concretions form the deleterious fraction of the aggregate. There are some boulders on site but cobbles up to 20 cm are the majority of the coarsest fraction. Lithology and grain size analysis are reported under site HG013 in Table GS-19-1. This year, two different gravel companies were crushing aggregate to produce traffic gravel for local roads. Klassen (1979) reported 18 m of coarse gravel in a water well in the adjacent quarter-section (NE-19-19-21-W1).

The pit at site HD222 in NE-32-19-19-W1 was also active in 1980 and is still very productive today. The pit is expanding eastwards; the active face is up to 5 m of crossbedded, very sandy, pebble gravel. Shale is again the most deleterious factor. Lithology and grain size analysis are reported under site HG081 in Table GS-19-1. The pit is owned and operated by one of the largest aggregate companies in the area.

The pit at site HD245 in SW-5-19-18-W1 is unusual in that the aggregate, unlike sites in the other outwash plain deposits, is overlain by 2–3 m of till. This amount of overburden is often considered enough to make gravel extraction uneconomic, however, there is >4 m of gravel under the till cap and this is a very active pit. The aggregate is crossbedded, very sandy, pebble gravel with a high shale content. There are stockpiles of traffic gravel on site. Two pits were sampled in this section during the 1980 study. Lithology and grain size analysis are reported under sites HG152 and HG154 in Table GS-19-1. In 1980, the pit in SE-5-19-18-W1 (HG154) was 5 m deep, it is now rehabilitated. As is common in ice-contact deposits, the gravel beds were faulted and highly contorted and overlain by till.

The outwash terrace deposits form a minor component of the aggregate resources in the municipality. The most well developed terrace deposits are along the Little Saskatchewan River; there are also small terraces along Heron Creek and Whirlpool River (Figure GS-19-2). The material in the deposits is most commonly sandy pebble gravel interbedded with sand. However, an exposure in NW-2-19-21-W1, visited in 1980, revealed 3 m of massive, poorly sorted, cobbly coarse gravel. The gravel was very shaly and ironstone concretions were common. The site is no longer exposed.

Aggregate regulations

Aggregate extraction is regulated through the Quarry Minerals Regulation (Manitoba Regulation 65/92) under *The Mines and Minerals Act* of Manitoba, through policies under *The Planning Act* and through municipal development plans and their zoning by-laws. Policy #9 under *The Planning Act* is designed to protect high quality mineral resources from conflicting land uses until the resource has been extracted. Most development plans include maps showing high quality aggregate deposits. Zoning by-laws identify where extraction is allowed or excluded; the by-laws may set strict land-use controls on mining.

The *Quarry Minerals Regulation* sets standards for such things as safety slopes, setbacks from adjacent property lines and waterways, noise levels and location of petroleum storage, etc. It also provides for the Pit and Quarry Rehabilitation program. Under this program, landowners can apply to have depleted or abandoned gravel pits and quarries rehabilitated to a standard that is "safe, environmentally stable and compatible with adjoining lands." For further information visit our website (http://www.gov.mb.ca/iedm/mrd/mines/acts/index.html).

Economic considerations

The value of aggregate reserves in any specific area depends on three things: abundance of the resources, the demand for the resources and the quality of the aggregate. The presence of shale in the aggregate will limit its potential uses. For many end uses, such as concrete, shale content must be less than 5%. Aggregate is a high-bulk, low-value commodity so haulage costs are an important factor that can cause a lower quality deposit to be used over a more distant higher quality deposit. The R.M. of Park has a large amount of aggregate and it is spread uniformly across the municipality. However, the shale content does lower the quality of the reserves and most of the aggregate is used for end products such as traffic gravel, which tolerates a higher percentage of shale. The fact that there are only four active pits in the municipality reflects the low quality of the deposits. The fact that two of them were active in 1980 and are not yet depleted reflects the substantial depth of material in some parts of the deposits and the sheer volume of aggregate per quarter section. The greatest demand for sand and gravel is in the eastern part of the municipality, near the south gate of Riding Mountain National Park. Cottage development and recreational facilities, such as golf courses, are on the increase there and are being built on aggregate deposits, however, the volume of aggregate in the areas of the nearby active pits (HD245 and HD222) is more than adequate to meet the needs for the foreseeable future. Land-use planning decisions should be based on maintaining a buffer around these pits to prevent any development from limiting their expansion in the future.

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GS-20 Summary of investigations for the Sedimentary and Industrial Minerals Section, Manitoba Geological Survey

by R.K. Bezys

Bezys, R.K. 2007: Summary of investigations for the Sedimentary and Industrial Minerals Section, Manitoba Geological Survey; *in* Report of Activities 2007, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 202–208.

Summary

The Sedimentary and Industrial Minerals Section of the Manitoba Geological Survey (MGS) conducted limited fieldwork in 2007 but many office-based projects were initiated or had new developments. The section is pleased to have hired a new stratigraphic and petroleum geologist this year. With the new hire, much progress was made on the Williston Basin Targeted Geoscience Initiative (TGI) project with all new content posted on the project's website. With the addition of a petroleum geologist to the section, the Devonian Three Forks Formation study is being expanded to improve understanding of the formation's oil-bearing capacity. Significant progress has been made with the Surficial Geology Compilation Map Series, which has been completed for the province and will be released in November 2007. Three stratigraphic coreholes were drilled in the summer of 2007, for a total depth of 166.1 m. Staff has also been responsible for responding to numerous requests for information on industrial minerals and aggregate deposits, as well as leading field trips. Some work has proceeded on the Phanerozoic lineament study and three-dimensional geological mapping of Manitoba. Support was also provided to the Manitoba Mineral Deposits Database and the Protected Areas Initiative Mining Sector Consultation.

Introduction

The Sedimentary and Industrial Minerals Section has had some new and exciting developments this year. The section is very excited to have M. Nicolas hired as our newest geologist. Her speciality is petroleum geology and stratigraphy and her main target of study in the short term will be the Devonian Three Forks Formation, along with the completion of the Williston Basin TGI project.

Other developments in the section include

- Williston Basin TGI project;
- Devonian Three Forks Formation petroleum study;
- Phanerozoic lineament study;
- Surficial Geology Compilation Map Series;
- three-dimensional geological mapping;
- 2007 Stratigraphic Corehole Drilling Program; and
- miscellaneous studies

Significant progress was made on the Williston Basin TGI project, with developments toward a new stratigraphic correlation chart, database compilation, biostratigraphy, hydrocarbon assessment, regional cross-sections and regional maps. All new information, as it comes available, has been posted on the TGI website (http://www.willistontgi.com). With the hire of M. Nicolas, the Devonian Three Forks Formation petroleum study will be expanded to include a detailed geoscientific study of the formation's oil-bearing capacity, as well as a reservoir analysis of the Sinclair Field (Nicolas, GS-17, this volume). The Phanerozoic lineament study, which is a co-operative study between the MGS, Saskatchewan Industry and Resources and the Alberta Geological Survey, has had some progress. The first phase of structural compilation is complete for Manitoba and the second phase of digitizing the lineaments will commence shortly. Considerable progress has been made on the Surficial Geology Compilation Map Series of Manitoba. The project is now completed and will be released on DVD (second edition) and as a 1:1 000 000 surficial geology map. Three-dimensional geological mapping of the province will continue into southwestern Manitoba in the upcoming year in support of the groundwater-related issues. Three coreholes were drilled in 2007 to assist in an understanding of Paleozoic stratigraphy and altered Mesozoic shale (Bamburak, GS-16, this volume). The section has been assisting with the compilation of the Manitoba Mineral Deposits Database (Heine, GS-21, this volume), as well as providing input to the Protected Areas Initiative Mining Sector Consultation in southeastern Manitoba. Aggregate studies were conducted in the Rural Municipality (R.M.) of Park as part of an ongoing project to update aggregate information in the province (Groom, GS-19, this volume).

Williston Basin TGI project

The Williston Basin TGI project was originally a two-year project, and is now in its fourth year. Despite the completion delays, it has proven to be extremely useful and informative to all who work in the Canadian portion of the Williston Basin. With the creation of the project's own website (http://www.willistontgi.com), all products from this project have been posted, as they come available, to ensure users are kept up to date. The high quality of science being conducted during the course of the project has not been compromised.

Below is a summary of the accomplishments for each task in the project.

1. **Geoscience knowledge inventory (bibliography)**
   - completed and ready to use on the website

2. **Regional geological mapping**
   - a detailed stratigraphic column has been completed for the project (see section below) to assist in cross-border mapping
   - biostratigraphy has been completed for several Mississippian and Cretaceous horizons (see section below)
   - the stratigraphic database contains a total of 9012 wells and is available on the website for free download
   - structure and isopach maps have been completed for 58 stratigraphic horizons, resulting in a total of 104 maps
   - a grid of regional cross-sections with geophysical logs and TGI stratigraphic picks is in progress
3. **Geophysical investigations**
   - regional gravity and high-resolution aeromagnetic maps were compiled for the Williston Basin within the study area, resulting in a seamless tectonic framework for the Precambrian basement rocks directly beneath the Phanerozoic cover
   - eight seismic lines were acquired for the project
4. **Regional hydrogeology**
   - a series of maps, consisting of total dissolved solids, freshwater head and water driving force for every hydrostratigraphic unit (19 in total from Precambrian to surface), have been completed, as well as the hydrochemical and hydraulic cross-sections
5. **Remotely sensed imagery**
   - with the exception of using sensing methods to help draw the outcrop edges of some of the Lower Paleozoic and Cretaceous horizons, this task was cancelled
6. **Hydrocarbon assessment**
   - oil and gas fields and pool boundaries, reserves information, oil and gas shows (outside producing zones), drill stem tests (DST), source rock information (total organic carbon [TOC] and Rock-Eval™) and vitrinite reflectance results have been compiled
   - a GIS-based map will be created to view the data
7. **Three-dimensional GoCad™ geological model**
   - the model will encompass the stratigraphy in south-western Manitoba, including all units from the Quaternary to the Precambrian
   - a preliminary version of this model is available on the website
   - the final model is still in progress
8. **Summary report**
   - As the project evolved, it was decided not to do one large report but to break it down into several reports, each discussing different aspects of the project, as outlined in the following:
     - a summary report on the results of the biostratigraphy for the Manitoba samples is in progress
     - a first draft of a detailed report on the Mesozoic sequence, covering the entire TGI area, has been completed
     - the geophysical report has been completed
     - the final hyrdogeological report is in progress
     - first drafts of the summary reports on the hydrocarbon assessment for the Paleozoic and Mesozoic sections in Manitoba have been completed

Stratigraphic correlation chart

With the staffing addition of M. Nicolas to the section, the TGI project has been moving towards completion. Presently the TGI stratigraphic correlation chart has been completed and is available for free download at http://www.willstontgi.com (Figure GS-20-1). This chart shows detailed crossborder correlations between eastern Saskatchewan and Manitoba of all formations and members within the Phanerozoic. The detail within the correlation chart (to member level) goes beyond the level of detail found in the published stratigraphic maps, which are also being produced for the TGI website. This chart is a state-of-the-art publication for this region of the Williston Basin, and will be the standard for future explorationists and researchers.

Biostratigraphy

Samples of core from the Mesozoic and Mississippian intervals for the TGI project were sent to the Geological Survey of Canada's (GSC) paleontology laboratory in Calgary for biostratigraphic analysis (conodont, foraminiferal and palynological analyses). Preliminary review of the conodont analyses of the Mississippian intervals in Manitoba show interesting timelines. The Mississippian samples analyzed were from the Lodgepole Formation's Daly Member, Cruikshank Crinoidal facies, Basal Limestone facies and the Routledge Shale facies, as well as the Bakken Formation's Upper Member. All samples from the Mississippian indicate deep-water deposition. The conodont colour alteration index (CA) for all samples from the Mississippian had a value of CA = 1, indicating the rocks are thermally immature. A detailed report on the biostratigraphy results from the Williston Basin TGI project will be posted on http://www.willstontgi.com by the end of 2007. Results from the Mesozoic foraminiferal and palynological analyses are still being processed.

Hydrocarbon assessment

The hydrocarbon assessment of the TGI project area is nearing completion. A compilation of oil and gas shows, publicly available geochemistry results (TOC and Rock-Eval™), and vitrinite reflectance results from the GSC for the entire Phanerozoic section covering the TGI study area has been completed and converted into a GIS-ready format. Reservoir tables for the major fields, pools and units in Manitoba have been compiled and will also be converted into a GIS-ready format. Once all the hydrocarbon assessment data has been compiled into a GIS format, the information will be made

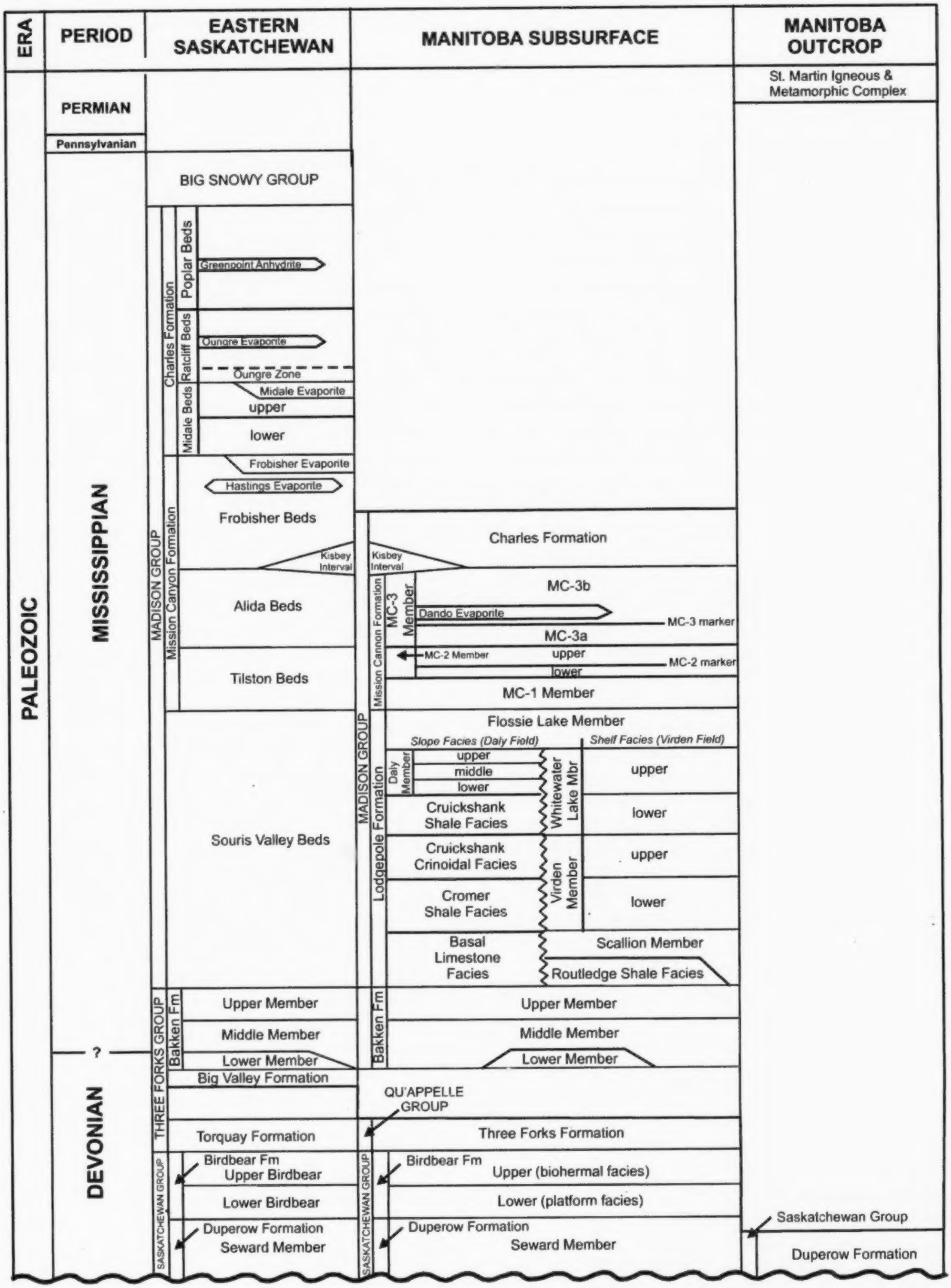
ERA
PERIOD
EASTERN SASKATCHEWAN
MANITOBA SUBSURFACE
MANITOBA OUTCROP
St. Martin Igneous & Metamorphic Complex
PERMIAN
Pennsylvanian
PALEOZOIC
MISSISSIPPIAN
DEVONIAN
?
BIG SNOWY GROUP
MADISON GROUP
Charles Formation
Poplar Beds
Greenpoint Anhydrite
Ratcliff Beds
Oungre Evaporite
Oungre Zone
Midale Beds
Midale Evaporite
upper
lower
Mission Canyon Formation
Frobisher Evaporite
Hastings Evaporite
Frobisher Beds
Kisbey Interval
Alida Beds
Tilston Beds
Souris Valley Beds
THREE FORKS GROUP
Bakken Fm
Upper Member
Middle Member
Lower Member
Big Valley Formation
Torquay Formation
SASKATCHEWAN GROUP
Birdbear Fm
Upper Birdbear
Lower Birdbear
Duperow Formation
Seward Member
Charles Formation
Kisbey Interval
MADISON GROUP
Mission Cannon Formation
MC-3 Member
MC-3b
Dando Evaporite
MC-3 marker
MC-3a
MC-2 Member
upper
lower
MC-2 marker
MC-1 Member
Lodgepole Formation
Flossie Lake Member
Slope Facies (Daly Field)
Shelf Facies (Virden Field)
Daly Member
upper
middle
lower
Whitewater Lake Mbr
upper
lower
Cruickshank Shale Facies
Cruickshank Crinoidal Facies
Virden Member
upper
lower
Cromer Shale Facies
Basal Limestone Facies
Scallion Member
Routledge Shale Facies
Bakken Fm
Upper Member
Middle Member
Lower Member
QU'APPELLE GROUP
Three Forks Formation
SASKATCHEWAN GROUP
Birdbear Fm
Upper (biohermal facies)
Lower (platform facies)
Duperow Formation
Seward Member
Saskatchewan Group
Duperow Formation

Figure GS-20-1: *The central portion of the Williston Basin Targeted Geoscience Initiative (TGI) stratigraphic correlation chart. The entire section can be viewed at http://www.willistontgi.com.*

available at http://www.willistontgi.com either as shapefiles or Excel® tables.

Regional cross-sections

An array of regional cross-sections, covering the TGI study area for the entire Phanerozoic section, is in the process of being completed. Preliminary cross-sections have been reviewed and will be posted on the website when completed.

Devonian Three Forks Formation study

A petroleum study of the Devonian Three Forks Formation, Qu'Appelle Group, in southwestern Manitoba is being expanded from a smaller study (Nicolas, 2006), originally undertaken as a core workshop at the Saskatchewan and Northern Plains Oil and Gas Symposium in October 2006. This expanded study includes the entire depositional area of the Three Forks Formation in Manitoba, from Twp. 1 to 23 and Rge. 13 to 29, W 1st Mer. A preliminary report discussing the early findings of this study is published in this volume (Nicolas, GS-17, this volume).

The expanded study includes core descriptions, isopach and structure maps of the formation, detailed maps of the units within the Three Forks Formation, tectonic environment, and controls on the formation's oil-bearing capacity. A reservoir analysis of the Sinclair Field and comparison of the Sinclair reservoir with other Three Forks Formation producing pools within the province will also be attempted. A final geoscientific report will be published in early 2008.

The discovery of the Sinclair Field in 2004 has sprouted a great interest in the Three Forks Formation in Manitoba – a formation overlooked for its petroleum potential in the past. The Sinclair Field has proven and probable reserves, estimated at 6.8 million m^3, and has attracted much attention from the petroleum industry. New drilling techniques and a better understanding of the geology of the Three Forks Formation has many petroleum companies exploring elsewhere in Manitoba's wedge of the Williston Basin to hopefully find another hidden field as successful and profitable as the Sinclair Field.

Phanerozoic lineament study

The first phase of the Phanerozoic structural compilation project of Manitoba's portion of the Western Canada Sedimentary Basin has been started by the MGS (Bezys, 2006). This initial phase involved the inventory of published maps and figures of lineaments in Manitoba. As a result of this work, over sixty documents were identified, from published works between 1957 and 2006.

The second phase of digitizing the lineaments into ArcView layers (i.e., shapefiles) and tagging the lineaments with attribute data will commence shortly. This data will be merged with GIS digital shapefiles from published sources and contributed to the joint Alberta, Saskatchewan and Manitoba database of Phanerozoic structural lineament information.

Surficial Geology Compilation Map Series

The Surficial Geology Compilation Map Series (SGCMS) in Manitoba, which addresses an increasing demand for consistent surficial geology information for applications such as groundwater protection, land management and mineral exploration, has been completed and will be released on DVD (second edition) and as a 1:1 000 000 surficial geology map at the annual mineral convention (Matile and Keller, 2007a, b). The final map compilation at 1:1 000 000 is being released as a two-sided hard copy map and will supersede the original surficial geology map that was released in 1981 (Nielsen et al., 1981). All SGCMS products are also available for download from http://www.gov.mb.ca/iedm/mrd/geo/gis/surfgeomap.html.

To accomplish this compilation, all paper copies of the most current and detailed surficial geology maps of various scales published by the GSC and/or the MGS were digitized. Polygons for several areas, which had been mapped more recently, were derived from digital geological maps. Soil mapping was used to fill gaps in geological mapping. Edge-matching of adjoining map sheets, polygon gaps and inconsistencies were rectified based on data from the shuttle radar topography mission digital elevation model (United States Geological Survey, 2007) as interpreted by the MGS.

Map polygons are linked to a database containing the original maps' legends compiled from the source publications. These map legend items are parsed into seven lithological and morphological characteristics allowing legend standardization across the province. The database consists of two tables: a 'legend link' table containing the parsed categories and derived legend and a second table housing the originally published legend descriptions. These two tables are linked to the polygon attribute table via a 'link' field. The linked polygons can be queried based on the above characteristics.

The maps are being released on DVD in PDF and shapefile formats. The 1:250 000 and 1:500 000 scale maps are also available on a print-on-demand basis. The SGCMS provides seamless province-wide coverage at three scales. The 1:250 000 and 1:500 000 scale maps include 1) hill-shaded surficial geology polygons; 2) a brief description of the landscape; 3) major landforms including glacial ice-flow direction; and 4) a paleogeographic reconstruction of late glacial events. The 1:1 000 000 scale map includes all of the information above as well as 1) a graphic description of map units including photographs and diagrams to define each unit in lay terms; 2) an index map of these photographs; 3) the effect of isostatic rebound on the Tyrrell Sea and major lakes; and 4) a 3-D block diagram (Figure GS-20-2).

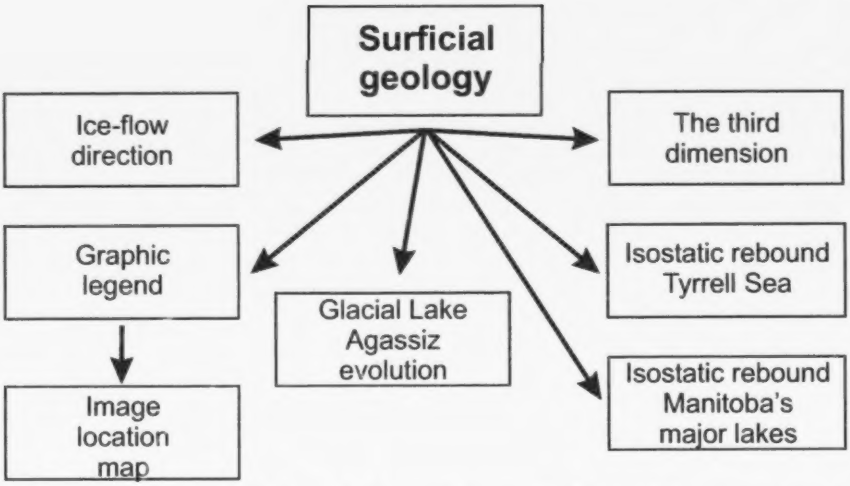
Surficial geology
Ice-flow direction
The third dimension
Graphic legend
Glacial Lake Agassiz evolution
Isostatic rebound Tyrrell Sea
Isostatic rebound Manitoba's major lakes
Image location map

Figure GS-20-2: *Flow chart diagram depicting the content of Manitoba's Surficial Geology Compilation Map Series, 1:1 000 000 scale maps.*

Three-dimensional geological mapping

Three-dimensional (3-D) geological mapping of the province will continue into southwestern Manitoba in the upcoming year in support of groundwater-related issues. The priority level of groundwater-related issues will steadily rise as the demand for water increases and surface water sources become fully allocated. Water supply, wetland protection, water quality protection and the ability to predict groundwater responses to drought, climate change or land-use change require a sound 3-D geological understanding to be properly addressed. While information systems are well developed for surface water in rivers and lakes, recent technological progress now allows a much more comprehensive management capability with respect to groundwater, the source of drinking water for about a quarter of all Manitobans. The possible transfer of groundwater from large aquifers in southeastern Manitoba to areas to the west has been the subject of recent discussions and is an example of a topic that requires optimal information to ensure good decision making. To that end, Manitoba Water Stewardship embarked on a drilling program in the fall of 2007 to help in the understanding of the aquifer systems in the Sandilands area of southeastern Manitoba (southeast of Steinbach; Figure GS-20-3). As well, the use of digital groundwater models by Manitoba Water Stewardship and consultants is increasing in response to the need for more quantitative groundwater assessments than have been carried out in the past. The likelihood that similar proposals will continue to arise on the U.S.A. side of the border, and the need to co-ordinate management of cross-border aquifers, indicate that these information systems need to be compatible across borders. Essential to this activity is 3-D geological mapping by MGS, which

Figure GS-20-3: *Rotosonic drill set-up in the Sandilands area of Manitoba.*

provides the framework or the 'geological vessel' for all wellwater management.

2007 Stratigraphic Corehole Drilling Program

Three stratigraphic coreholes were drilled in the summer of 2007 by the MGS. Two of the coreholes were drilled in Paleozoic strata to obtain better recovery of coreholes originally drilled in 2006 near Duck Bay and along PR 271. A third corehole was drilled on the east bank of the Valley River, northwest of Dauphin, to test the areal extent of an altered Mesozoic shale. Details of the drill results (including the possible discovery of hydrothermally altered dolomite) are described elsewhere in this volume (Bamburak, GS-16, this volume). Three holes, totalling 166.1 m, were drilled this year.

Miscellaneous studies

Numerous other studies and projects are carried out by the section.

Manitoba Mineral Deposits Database

The section is assisting with the compilation of the Manitoba Mineral Deposits Database, which will be based on the MGS Mineral Deposit Series (MDS). The design of the data input screens have been completed and work is progressing on populating the defined fields. To expedite the inclusion of this information, the MDS reports have been parsed and inserted into the appropriate database fields. This process is largely complete. Information from the Mineral Inventory Cards is also being incorporated. The fields that contain information from the MDS reports and Mineral Inventory Cards need to be edited to remove extraneous, non-acceptable characters and to confirm the accuracy of the entries. For further information on this project, please see Heine (GS-21, this volume).

Aggregate studies and Protected Areas Initiative Mining Sector Consultation

This summer, aggregate deposits in the R.M. of Park (adjacent to the south side of Riding Mountain National Park and encompassing six townships) were mapped due to increasing pressure for recreational subdivisions on prospective aggregate deposits (Groom, GS-19, this volume). The purpose of this study was to identify areas of best quality aggregate to be protected for extraction purposes. The last update of this municipality was done in 1980, as part of the South Riding Mountain project (Groom, 1980a, b; Young, 1983). Sites inspected include recently active pits and revisits to old extraction sites from the 1980 study.

The Protected Areas Initiative Mining Sector Consultation focused on site selection in natural region 5C (southeast Manitoba), with hopes of acquiring adequate representation for the region. Most sites were of organic material and the major concerns to industry were related to areas with the potential for peat extraction. Only one site visited affected an active gravel deposit. A few sites had bedrock quarry potential for crushed stone. This set of sites is completed.

Industrial minerals

The industrial minerals potential for the rural municipalities of Miniota, Archie and Rossburn were investigated during the field season. This information will be used in municipal development plans, resource management studies, Protected Areas Initiative Mining Sector Consultation studies and for use by other government departments and clients. Results of these investigations are described elsewhere in this volume (Bamburak, GS-18, this volume).

Field trips and presentations

The Sedimentary and Industrial Minerals Section provided numerous field trips and presentations during 2007. Field trips were conducted for staff of the Canadian Fossil Discovery Centre, participants of the Manitoba Paleontology Seminar, and to staff of one petroleum company. Sites visited included Paleozoic limestone and dolomite outcrops of the Williston and Elk Point basins and Cretaceous shale exposures of the Manitoba Escarpment.

Presentations were made at two of the monthly meetings of the Mineral Society of Manitoba. Topics discussed included the Lake St. Martin cryptoexplosion crater and the Pemmican Island Mississippi Valley-type occurrence. Industrial and metallic minerals talks were presented to residents of the rural municipalities of Miniota, Archie and Rossburn.

Economic considerations

Large regional syntheses, such as the Williston Basin TGI and lineament compilation projects, are the framework upon which subsequent exploration will be based. The TGI project has shown that interprovincial subsurface correlations are invaluable and represent a significant accomplishment. This is best reflected in the new stratigraphic correlation chart and database of the study area that are now available for viewing on the website. This information, along with the detailed crossborder Mesozoic correlations, will be of assistance to the petroleum exploration industry in southwestern Manitoba.

The discovery of the new Sinclair Field (conventional oil) in southwestern Manitoba coincided with the crossborder correlations of the Bakken and Three Forks formations, which were part of last year's TGI project. Industry has benefited from the co-operative mapping project and discussions between Manitoba and Saskatchewan in understanding the dynamics of this exciting new play. Further study of the Devonian Three Forks Formation in Manitoba will hopefully see an expansion of the play beyond the boundaries of the Sinclair Field.

It is hoped that further hydrocarbon and mineral exploration will be conducted in Manitoba as a result of the lineament compilation study, Manitoba Mineral Deposits Database and stratigraphic coreholes drilled. Surficial mapping and aggregate studies are important for effective land-use planning, and hydrocarbon, groundwater and industrial minerals development.

Acknowledgments

The author thanks all staff of the Sedimentary and Industrial Minerals Section who made contributions to this report. They include J. Bamburak, H. Groom, G. Keller, P. Leskiw, G. Matile and M. Nicolas and a special thanks to T. Heine, who made contributions to the Manitoba Mineral Deposits Database (Mineral Deposit Section). J. Bamburak kindly edited this report.

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GS-21 Manitoba Mineral Deposits Database

by T.H. Heine

Heine, T.H. 2007: Manitoba Mineral Deposits Database; in Report of Activities 2007, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 209–210.

Summary

The design of a series of data input screens in the Oracle® database for the Manitoba Mineral Deposits Database (MDD) has now been completed and work is progressing on populating the defined fields. The initial source of information is the 33 reports of the Mineral Deposit Series (MDS). To expedite the inclusion of this information, these reports have been parsed and inserted into the appropriate database fields. This process is largely complete. Information from the Mineral Inventory Cards is being incorporated at the same time. The fields that contain information from the MDS reports and Mineral Inventory Cards need to be edited to remove extraneous unacceptable characters and to confirm the accuracy of the entries.

Introduction

The desirability of creating an inventory of all presently known mineral deposits and occurrences in the Province of Manitoba has long been recognized by the Manitoba Geological Survey. As a result, several efforts have been made to summarize the mineral inventory of the province. Bamburak (1980) has provided an excellent summary of the early efforts at establishing such an inventory.

Mineral Inventory Cards

The 'modern' era of deposit documentation started in 1973 with the National Mineral Inventory, a joint federal-provincial project. This resulted in the creation of a series of Mineral Inventory Cards for Manitoba (Bamburak, 1980). These were designed to provide concise descriptions of metallic mineral deposits and occurrences throughout Canada. In part, these cards provided a starting point for mineral exploration and mining companies to gather additional information to guide their efforts. Once this project was completed, the index was kept up to date on an *ad hoc* basis. An update was published by Athayde (1991), and the cards were periodically updated until about 1992. Various efforts were made to export and/or save this information into a digital format that could be easily revised and where additional deposits and occurrences could be added. These proved to be largely unsuccessful, but the Mineral Inventory Cards are available online from the Mineral Resources Library at http://www2.gov.mb.ca/itm-cat/multisearch.htm.

One project that used the Mineral Inventory Card system was to assist in the assessment of the massive sulphide deposit potential of Manitoba. This culminated in the publication of a report that included 23 maps of massive sulphide potential (Gale et al., 1980).

Mineral Deposit Series

Publication of the Mineral Deposit Series reports took place during the period 1988–2003 and was limited to areas that had seen significant mining and mineral exploration activity. For the most part, the publications were organized as reports that covered single 1:50 000 scale National Topographic Series map areas. Fifty-three of the total provincial coverage of 744 sheets were documented. As with the Mineral Inventory Cards, the descriptions were designed to provide a uniformly organized summary of information about individual deposits and occurrences, including references where additional and more detailed data could be obtained.

Some effort was made to expand the coverage of the MDS reports into the area underlain by the northern Superior Province, and mineral deposits and occurrences for NTS sheets 53K, L, M and N, and 63I and P have been documented. These descriptions have remained unpublished but are available in digital format and will be incorporated into the MDD.

Manitoba Mineral Deposits Database

Nondigital precursors to this database had a number of drawbacks and limitations. It was neither a searchable data set, nor was it easy to revise or update existing descriptions or add new ones. The MDS reports suffered a further limitation in that they covered only a limited number of topographic areas.

A digital format was required in order to create a usable relational database. The broad structure of the database has been described previously (Heine, 2006). To some degree, the data fields of the database parallel those of the previously described text-based compilations. The MDS reports had been produced largely using various word-processing programs, and were thus available in a digital format. These text files could be easily parsed and entered into the appropriate database fields. This information has provided the foundation information for the MDD. Most of these files have been imported into the database. In addition, many of the Mineral Inventory Cards are available in digital format, and parts of these files can easily be copied and inserted into the appropriate fields. Current efforts are concentrated on editing information that has been imported from the MDS reports and Mineral Inventory Cards and ensuring that there are no formatting sequences that may cause problems for the database program (Oracle®) and to confirm that the information is correct.

Once the information from the MDS reports and Mineral Inventory Cards has been edited, nonconfidential assessment files will be reviewed to update existing information, expand the areal coverage of the database to include the entire province and add new occurrences.

Economic considerations

The creation of a searchable digital mineral deposits and occurrences database for the Province of Manitoba has been a goal of the Manitoba Geological Survey for a number of years. This database is targeted specifically at the mineral exploration and mining industries. The information contained within it will serve to summarize the nonconfidential work that has been performed on specific properties, thereby enabling geologists to quickly make decisions on where future efforts should be concentrated, in order to further evaluate occurrences and deposits. References included in the database allow users to find additional information for particular occurrences.

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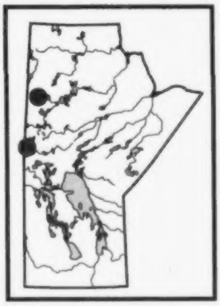
GS-22 Manitoba's Precambrian Drillcore Libraries Program

by D.E. Prouse

Prouse, D.E. 2007: Manitoba's Precambrian Drillcore Libraries Program; *in* Report of Activities 2007, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 211.



Summary

Manitoba's Mineral Resources Division has been storing Precambrian drillcore, obtained primarily from exploration drilling, since the early 1970s. Since that time, the Manitoba government has created a substantial repository of drillcore at five locations throughout the province. Funding to help build a significant inventory of drillcore to represent crucial stratigraphy within Manitoba's principal mining districts has been sporadic since the collection was started. Since 2001, funding has allowed the department primarily to maintain drillcore inventories at current levels, with some additions being made to the Thompson and Lynn Lake facilities.

Introduction

The Manitoba Mineral Resources Division considers the archiving of exploration drillcore to be a valuable data source for use by mineral-exploration companies and researchers. For this reason, the province has retrieved and stored Precambrian drillcore since the early 1970s. Core-storage facilities were constructed at The Pas, Thompson and Lynn Lake in the early 1970s, which provided the necessary space to establish a comprehensive drillcore collection. A storage facility was acquired in Winnipeg in 1980 to store drillcore from southeastern Manitoba. This acquisition meant that there was now a storage facility for drillcore collected from all of Manitoba's major mining districts. In 1993, the Manitoba Geological Survey established an expediting base at the former Centennial minesite near Flin Flon. The site also provides secure outside storage for drillcore obtained from company exploration programs conducted in the Flin Flon area.

It is estimated that the Manitoba Geological Survey's Precambrian drillcore libraries contain 260 000 m of core. This figure includes about 20 000 m of Precambrian core stored at the department's Midland Rock Lab in Winnipeg. The estimate does not include core stored at the Centennial site or recent additions to Thompson and Lynn Lake.

How to use Manitoba's drillcore libraries

All five core libraries have lighted, heated inspection rooms with benches, and most have core splitters. **Since the core libraries are not permanently manned, all enquiries and requests for access to any of the northern libraries must be made to**

Dave Prouse, Resident Geologist
Manitoba Geological Survey
Manitoba Science, Technology, Energy and Mines
143 Main Street, Suite 201
Flin Flon, Manitoba R8A 1K2
Telephone: (204) 687-1632
E-mail: Dave.Prouse@gov.mb.ca

Access to view core at the Brady Road facility in Winnipeg should be arranged with

Jim Payne, Assessment Geologist
Mines Branch
Manitoba Science, Technology, Energy and Mines
1395 Ellice Avenue, Suite 360
Winnipeg, Manitoba, R3G 3P2
Telephone: (204) 945-6535
Email: James.Payne@gov.mb.ca

Once permission has been granted to view nonconfidential core in a specific library, arrangements will be made for the user to obtain keys to that facility. Keys for access to the Centennial compound near Flin Flon can be obtained from the local Manitoba Geological Survey office. Access to the Lynn Lake, Thompson and The Pas libraries must be arranged with the Resident Geologist in Flin Flon.

Companies or individuals wishing to donate and place core in any of Manitoba's northern drillcore libraries must first obtain permission from the Resident Geologist in Flin Flon. In the case of the core library in Winnipeg, permission must be granted from the Assessment Geologist. Core boxes placed in a library will be managed by Manitoba Science, Technology, Energy and Mines personnel. Removal of core boxes from the library premises is not permitted. Users wishing to examine core must be prepared to physically handle the core boxes and return them to their original storage location. Permission is required to sample core contained in any of the province's core libraries. Assay results and pulps from these samples must be forwarded if requested. Quartering of previously sampled core is not permitted except in rare circumstances.

Economic considerations

Diamond drilling of a mineral prospect is the most important and costly phase in the evaluation of any mining property. The preservation of drillcore can help reduce costs of redrilling these prospects as exploration techniques and geological concepts evolve. Archived core also serves as a valuable asset to researchers, especially in areas of extensive overburden or, as in Manitoba's case, where Paleozoic cover rocks overlie Precambrian basement rocks.

PUBLICATIONS

PRELIMINARY MAPS

PMAP2007-1	Geology of the Flin Flon area, Manitoba (part of NTS 63K12) by R-L. Simard, P.D. Kremer, K. MacLachlan, Y.M. DeWolfe, H. Gibson, B. LaFrance, D. Ames, A.H. Bailes, C. Devine, D. Price and S. Pehrsson	scale 1:10 000
PMAP2007-2	Revised geology of Notigi Lake, Manitoba (NTS 63O14 and parts of 64B3) by L.A. Murphy and H.V. Zwanzig	scale 1:20 000
PMAP2007-3	Revised geology of the Kawaweyak Lake area, Manitoba (part of NTS 63O15) by L.A. Murphy and H.V. Zwanzig	scale 1:10 000
PMAP2007-4	Bedrock geology of the Utik Lake greenstone belt, Manitoba (parts of NTS 53M4, 5, 63P1, 8) by C.O. Böhm and P.D. Kremer	scale 1:25 000
PMAP2007-5	Geology of the east part of the Bird River area, southeastern Manitoba (part of NTS 52L6) by H.P. Gilbert	scale 1:20 000
PMAP2007-6	Geology of the west part of the Bird River area, southeastern Manitoba (part of NTS 52L5) by H.P. Gilbert	scale 1:20 000

PUBLICATIONS RELEASED NOVEMBER 2006 TO NOVEMBER 2007

Manitoba Geological Survey Reports and Maps

Geoscientific Paper

GP2006-1

New uranium-lead geochronology results from the Lynn Lake greenstone belt, Manitoba (NTS 64C11–16) / by C.J. Beaumont-Smith, N. Machado and D.C. Peck

Open File Reports

OF2006-32

Bedrock geology of the Gull Rapids area, Manitoba (part of NTS 54D6) / by C.O. Böhm, M.S. Bowerman and M.W. Downey (Digital map on DVD)

OF2006-33

Thompson Nickel Belt geological compilation map, Manitoba (parts of NTS 63G, J, O, P and 64A and B) / by J.J. Macek, H.V. Zwanzig and J.M. Pacey (Digital map on CD-ROM)

OF2006-34 (Supercedes OF2005-3)

Manitoba Geochronology Database / by Manitoba Geological Survey (Digital web release only)

Surficial Geology Compilation Map Series

SG-CMS

Surficial Geology Compilation Map Series of Manitoba / by G.L.D. Matile and G.R. Keller (Digital maps on DVD)

Preliminary Maps

PMAP2006-1

Geology of the Schist Lake–Mandy mines area, Flin Flon, Manitoba (parts of NTS 63K12) / by R.-L. Simard (scale 1:5000)

PMAP2006-2

Bedrock geology of the Bear Lake area, Manitoba (parts of NTS 53M4 and 63P1) / by C.O. Böhm and R.P. Hartlaub (scale 1:50 000)

PMAP2006-3

Revised geology of the Wuskwatim–Threepoint lakes area, Manitoba (NTS 63O10 and parts of 63O11) / by H.V. Zwanzig, J.A. Percival and L. Murphy (scale 1:50 0000)

PMAP2006-4

Bedrock geology of the Kasmere Lake area, Manitoba (NTS 64N11 and parts of NTS 64N6) / by C.O. Böhm and S.D. Anderson (scale 1:50 000)

PMAP2006-5

Bedrock geology of the Putahow Lake area, Manitoba (NTS 64N15) / by S.D. Anderson and C.O. Böhm (scale 1:50 000)

PMAP2006-6

Surficial geology of the Kasmere–Putahow lakes area, northwestern Manitoba (parts of NTS 64N10, 11, 14 and 15) / by G.L.D. Matile (scale 1:50 000)

PMAP2006-7

Geology and structure of the Garner Lake–Gem Lake area, Rice Lake greenstone belt, Manitoba (NTS 52L11 and 14) / by S.D. Anderson (scale 1:20 000)

PMAP2006-8

Geology of the east-central part of the Bird River area, Manitoba (NTS 52L6N) / by H.P. Gilbert (scale 1:20 000)

PMAP2006-9

Geology of the Bernic Lake area around the Tanco mine, Bird River greenstone belt, southeastern Manitoba (NTS 52L6) / by P.D. Kremer and S. Lin (scale 1:10 000)

PMAP2006-10

Geology of the Bird River Sill, southeastern Manitoba (part of NTS 52L5) / by by C. Mealin (scale 1:50 000)

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Annual review / by E.C. Syme, p. 1-8.

FLIN FLON–SNOW LAKE

GS-1

Geology of the Schist Lake–Mandy mines area, Flin Flon, Manitoba (part of NTS 63K12) / by R-L. Simard, p. 9-21.

GS-2

Stratigraphic subdivision of the Hidden and Louis formations, Flin Flon, Manitoba (NTS 63K16SW) / by Y.M. DeWolfe and H.L. Gibson, p. 22-34.

GS-3

Wonderland gabbro: U-Pb age and geological implications, Manitoba (NTS 63K12NE) / by A.H. Bailes and P. Theyer, p. 35-41.

GS-4

Metallogenic and metamorphic study of selected deposits from the Snow Lake area and the southern flank of the Kisseynew Domain, Manitoba (NTS 63K16 and 63N2) / by S. Gagné, C.J. Beaumont-Smith, A.E. Williams-Jones and A. Hynes, p. 42-48.

GS-5

Igneous carbonate-rich rocks from the south Wekusko Lake area, Manitoba (parts of NTS 63K9 and 63J12): a kimberlite-carbonatite dilemma / by A. Chakhmouradian, C.O. Böhm and J.K. Greville, p. 49-62.

GS-6

Activities of the Manitoba Geological Survey's Flin Flon regional office / by T.H. Heine, p. 63-64.

SUPERIOR PROVINCE

GS-7

Preliminary results from geological mapping of the Bear Lake greenstone belt, Manitoba (parts of NTS 53M4 and 63P1) / by R.P. Hartlaub and C.O. Böhm, p. 65-73.

SUPERIOR BOUNDARY ZONE, THOMPSON NICKEL BELT

GS-8

New tectonostratigraphic framework for the northeastern Kisseynew Domain, Manitoba (parts of NTS 63O) / by J.A. Percival, H.V. Zwanzig and N. Rayner, p. 74-84.

GS-9

Thompson Nickel Belt–type units in the northeastern Kisseynew Domain, Manitoba (parts of NTS 63O) / by H.V. Zwanzig, L. Murphy, J.A. Percival, J.B. Whalen and N. Rayner, p. 85-103.

GS-10

Regional granulite-facies metamorphism in the northeastern Kisseynew Domain, Manitoba (parts of NTS 63O) / by M.L. Growdon, J.A. Percival, N. Rayner and L. Murphy, p. 104-115.

GS-11

Detrital zircon provenance of the Pipe Formation, Ospwagan Group, Thompson Nickel Belt, Manitoba, NTS 63O8 / by N. Rayner, H.V. Zwanzig and J.A. Percival, p. 116-124.

GS-12

Preliminary field observations of regional metamorphism in the Thompson Nickel Belt, Manitoba (parts of NTS 63J15, 63O1 and 2, 63O8 and 9, 63P12 and 13) / by C.G. Couëslan, D.R.M. Pattison and J.J. Macek, p. 125-135.

FAR NORTH

GS-13

Preliminary results from geological bedrock mapping of the Kasmere and Putahow lakes areas, northwestern Manitoba (parts of NTS 64N6, 10, 11 and 15) / by C.O. Böhm and S.D. Anderson, p. 136-147.

GS-14

Surficial geological investigations in the Kasmere–Putahow lakes area, northwestern Manitoba (parts of NTS 64N10, 11, 14 and 15) / by G.L.D. Matile, p.148-154.

SOUTHEASTERN MANITOBA

GS-15

Update and economic significance of geological mapping in the Garner–Gem lakes area, Rice Lake greenstone belt, southeastern Manitoba (NTS 52L11 and 14) / by S.D. Anderson, p. 155-169.

GS-16

Geology and structure of the Bird River Belt, southeastern Manitoba (NTS 52L5 and 6) / by M. Duguet, H.P. Gilbert, M.T. Corkery and S. Lin, p. 170-183.

GS-17

Geological investigations in the Bird River area, southeastern Manitoba (parts of NTS 52L5N and 6) / by H.P. Gilbert, p. 184-205.

GS-18

Structural geology of the Bernic Lake area, Bird River greenstone belt, southeastern Manitoba (NTS 52L6): implications for rare element pegmatite emplacement / by P.D. Kremer and S. Lin, p. 206-213.

GS-19

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